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PREFACE

NASA's Stennis Space Center (SSC) is the designated Center of Excellence for large space propulsion system testing and rocket test technologies. The Space Shuttle Main Engine (SSME) is tested at SSC for improvement, development, and flight readiness. Since 1987, SSC has been an advocate and leader in rocket engine exhaust plume diagnostics, vehicle health management (VHM), and propulsion ground testing technology. The near-term objective of the rocket exhaust plume diagnostics program is to enhance test operation efficiency and to provide for safe cutoff of rocket engines prior to incipient failure, thereby avoiding the destruction of the multimillion dollar engine and test complex, and preventing delays to a national priority space program. SSC pursues its technology and advanced development program in plume diagnostics within a cooperative infrastructure of other NASA program offices and centers, academia, the rocket industry, and technical services contractors.

To date, the focus in rocket engine exhaust plume diagnostics at SSC has been based on emission spectroscopy of the exhaust plume and applying the technology to the three large SSC test stands. Over 98,000 seconds of plume spectral data on SSME tests have been collected. In addition, more than 12,000 seconds of unique spectral data have been obtained at the Diagnostics Testbed Facility (DTF) at SSC. The small-scale DTF rocket engine enables the study of exhaust plume flowfields and development of plume diagnostics instrumentation, sensor systems, and techniques. The DTF Thruster (DTFT) is used to replicate SSME exhaust plume conditions and to produce calibrated plume spectra of elements and materials potentially present in the hot gas path of the SSME.

An increased understanding of the spectral data is leading to their use with other more traditional ground test data and providing the knowledge base to develop software systems for analyzing the severity of SSME component wear and remaining life. This report provides the results of an experimental program specifically dedicated to the collection and analyses of high-resolution spectral data for development of this requisite knowledge base. This information is being presented to the NASA and aerospace community at a time when vehicle health monitoring has become a necessity for lowering life cycle costs and assuring mission success. The line identification, line interference, and spectral characteristic data presented herein should be of particular importance to developing those sensors based on emission or absorption spectroscopy for integrated health and condition monitoring.

Presented herein are the spectral data for the 10 most important SSME elements and 27 most important SSME materials which are strongly to moderately emitting in the DTFT exhaust plume. The covered spectral range is 300 to 426 nm and the spectral resolution is 0.25 nm. A summary and discussion of significant results are given. Spectral line identification information is provided and line interference effects are considered. The experimental systems and associated equipment used to generate and acquire the high-resolution spectral data are also described. Complete details and discussion of the DTFT and dopant injection parameters are given in Appendix A. Exhaust plume spectra and spectral line identification tables for the SSME elements and alloys are presented in Appendixes B and C, respectively.

The evaluation study presented herein was performed under the auspices of the Science and Technology Laboratory at SSC and by the Engineering and Science Department of Sverdrup Technology, Inc., SSC Group, under NASA contract number NAS13-290. Efforts were conducted under Technical Work Requests (TWR) J9A0-T102 and J1E0-AT02 during FY91 and FY92, respectively.

The study could not have been completed without the dedicated and cooperative efforts of many individuals and groups working together as a team. Sponsorship and advocacy from NASA HQ has been provided by David L. Winterhalter, Code ME; Paul N. Herr and Charles T. Holliman, Code MD; and William J.D. Escher of Code RP. NASA/SSC Technical Monitor, Bruce A. Spiering, is acknowledged for his project guidance during FY92. The constant maintenance and upgrade of DTF equipment to meet testing requirements, along with patient cooperation in test scheduling and the sharing of space with experimenters, have been vital to achieving the results presented here. The DTF Operations Team, with Nickey Raines Test Conductor, is to be commended. Nickey G. Raines provided the write-up for Appendix A of this report. The quality of dopant solutions for DTF plume seeding experimentation was assured by K.E. Trawick of the SSC Gas and Materials Analysis

Laboratory. Aubry Harris provided critical software programming support and assured its successful implementation. The spectral data could not have been collected without the outstanding efforts of Electro-Optical Technicians Greg McVay, Cory Stewart, and Lester Langford. Data reduction and analyses could not have been completed without the superb assistance of Peggy Guillot. She also, with diligence and great care, prepared the figures on exhaust plume spectra utilized in this report. Finally, Ruth Anderson and Margaret Pharr provided expert assistance in the preparation of tables, typing, figure layout, organization, and editing of this report for its publication.

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INTRODUCTION

Exhaust plume emission spectroscopy is emerging as a comprehensive nonintrusive sensing technology which can be applied to a wide variety of engine performance conditions with a high degree of sensitivity and specificity.[1] Stennis Space Center (SSC) has been in the forefront of advancing experimental techniques and developing theoretical approaches in order to bring this technology to a more mature stage. The current focus of these efforts is the Space Shuttle Main Engine (SSME). SSME exhaust plume spectral data have been routinely acquired at the SSC test stands since 1989 by utilizing an Optical Multichannel Analyzer (OMA)-based system. Initially the covered spectral range was from 300 to 830 nm with a spectral resolution of about 2 nm.[2] This low resolution and correspondingly low sensitivity was found to be inadequate for detailed, more precise spectral identifications and analyses.[3,4] Therefore, in September 1990, a high-resolution OMA-based system was added at the A-1 Test Stand for acquiring spectral data from 320 to 440 nm with a spectral resolution of about 0.25 nm. But, regardless of resolution or spectroscopic technique used, specific information on the SSME components and materials in the hot-gas path which erode (normally or abnormally) into the exhaust plume is critical to a qualitative and quantitative interpretation of the plume's spectral features and subsequent correlation of those features to engine performance conditions.

A study carried out at SSC in 1989 established a database of SSME critical components and materials.[5] This widely used and referenced study contains information on SSME components and fabrication materials, their nominal elemental composition, operating environments, and possible degradation modes. SSME components and materials and their constituent elements are prioritized depending upon the severity of their operating environments and the consequent likelihood of degradation modes. Those effluent materials and their constituent elements which are most likely to appear in the exhaust plume are given Priority Group 1. Priority Group 2 effluent materials and elements are less likely to appear and/or be observed or distinguished in the exhaust plume. Priority Group 3 effluent materials and elements are least likely to appear and/or be observed or distinguished in the exhaust plume. Information on spectral parameters such as line positions, line widths, and line intensities at the temperature and pressure conditions in the exhaust plume along the line of observation is needed for SSME materials and elements so the measured spectral data can be analyzed for the presence and amount of specific elements and materials.

Although there are sufficient spectral data in the published literature on line positions for elemental and molecular species of interest to the SSME plume diagnostics program, the relative line intensities and the line shapes are not well known for SSME exhaust plume conditions. Also, the available spectral data in the literature are limited to constituent elements; the emission spectra of most SSME alloys have not been investigated.

The Diagnostic Testbed Facility (DTF) at SSC was designed and constructed in 1988 to provide a testbed for development of rocket engine exhaust plume diagnostics methodologies and instrumentation. A 1200-lbf liquid oxygen/gaseous hydrogen thruster is used as a plume source for experimentation and instrument development.[6,7] It has been shown that the temperature and pressure conditions of the SSME exhaust plume in the first Mach diamond are very nearly replicated in the first Mach diamond of the DTF Thruster (DTFT).[8] The DTFT is equipped with a plume-seeding device which allows liquid seeding materials (dopants) to be introduced into the combustion chamber at the propellant injector faceplate.

The DTF with its thruster and dopant injection system provides a relatively inexpensive means for obtaining extensive sets of exhaust plume spectral data for the SSME-related elements and materials mentioned earlier. A prioritized list of elements for DTF seeding experiments is reproduced from Ref. 5 and given in Table 1. A similar list for SSME materials is given in Table 2. The ranking of materials and elements within each priority group is specified in Ref. 5.

This study presents the high-resolution spectra for the Group 1 and Group 2 SSME elements and Group 1 and Group 2 SSME materials. Spectral line identification information is tabulated. The known amounts of the SSME elements and materials were simulated in the DTFT exhaust plume by injecting dopants into the engine in the form of aqueous chemical solutions. Dopant solutions were prepared using Standard Reference Materials (SRMs) spectrometric standard solutions. The certified standards are traceable to the National Institute

Table 1. Prioritized List of Elements for DTF Seeding Experiments.

GROUP 1 (TOP PRIORITY)	GROUP 2 (INTERMEDIATE PRIORITY)	GROUP 3 (LOW PRIORITY)
Ni	Al	F
Fe	Ti	Cl
Cr	Ag	C
Co	Sn	Zn
Cu	Hf	Li
Ca	V	Rh
W	Y	Pd
Mn	Au	
Mo	Mg	
	Si	
	Ta	
	Nb	
	Zr	
	Be	

Table 2. Prioritized List of Materials for DTF Seeding Experiments.

GROUP 1 (TOP PRIORITY)	GROUP 2 (INTERMEDIATE PRIORITY)	GROUP 3 (LOW PRIORITY)
Inconel 718	347 CRES	ZrO_2
Haynes 188	A-286 CRES	Tungsten Carbide
MAR-M 246+Hf	Inconel 625	$MoSi_2$
Waspaloy X	Inconel 600	316L CRES
AISI 440C	Incoloy 903	304 CRES
NARloy-Z	Inconel X-750	321 CRES
MoS_2	Armco 21-6-9	302 CRES
NiCrAlY	K-Monel	304L CRES
$ZrO_2 \cdot 8\%\ Y_2O_3$	Ti-5Al-2.5Sn ELI	420 CRES
PTFE	Ti-6Al-6V-2Sn	303 CRES
Armalon	Tens-50 Aluminum	301 CRES
	6061 Aluminum	LiF
	Hastelloy B	Kel-F
	Hastelloy B-2	Vespel SP-211
	Hastelloy X	Polyurethane
	Rene 41	Epoxy Resin
	Waspaloy	Buna N
	Incoloy 88	
	Nickel Palladium	
	Elgiloy	
	NARloy-A	
	Nitriding Steel	
	2024 Aluminum	
	A356 Aluminum	
	Beryllium Copper	

of Standards and Technology (NIST). These stock solutions, which are highly concentrated in a matrix containing small amounts of acid (usually HCl or HNO_3), are mixed and diluted according to the DTF testing requirements. Further details are given later in this report.

The spectral range for the data presented herein is 300 to 426 nm and the spectral resolution is 0.25 nm. A brief description of the DTFT along with the experimental setup, including the calibration and data reduction procedure, is given in Section II. A detailed description of the facility and its operations is provided in Appendix A. The spectral data for the 10 Group 1 and Group 2 elements and 27 Group 1 and Group 2 materials which are strongly to moderately emitting in the DTFT exhaust plume are discussed in Section III. Line identification information is also given for these elements and alloys in Section III. Priority Group 1 and Group 2 elements and Priority Group 1 and Group 2 materials which have not been tested or which have been tested but whose spectral data are not included are briefly mentioned in Section III. The figures and tables pertinent to the discussions in Section III are presented in Appendixes B and C. The application of this spectral data compilation to the SSC engine testing program is discussed in Section IV, and a brief summary and concluding remarks are presented in Section V.

EXPERIMENTAL PROGRAM

The experimental setup used to obtain the spectral database of SSME-related elements and materials is presented in this section. Facility apparatus include: (a) DTFT, (b) associated hardware used to generate the plume source, and (c) dopant injection system. Other experimental apparatus include the spectroscopic data acquisition system which consists of: (a) collection optics, (b) fiber optic cable, (c) spectrometer, (d) photodiode detector, (3) Optical Multichannel Analyzer (OMA), and (f) personal computer. Details of the calibration techniques used for the spectral data acquisition are also discussed.

Plume Source

A small-scale, low-thrust, pressure-fed rocket engine with the capability to inject small amounts of materials (dopants) into the combustion chamber and thus simulate SSME component wear was required as the plume source for experimentation. A nominal 1200-lbf engine designed specifically for non-flight research and development was selected.[6,7] The DTFT uses gaseous hydrogen (GH_2) and liquid oxygen (LOX) as fuel and oxidizer, respectively. Operating conditions were optimized to produce a plume with temperature and pressure conditions at the first Mach diamond as much like the SSME plume as possible.[8] Typical operating parameters for plume diagnostics and engine health monitoring experimentation are a combustion chamber pressure of 500 psia and a mixture ratio or oxidizer-to-fuel (O/F) ratio of 5.0. For these operating conditions, the calculated temperature and pressure downstream of the Mach disc is 3036 K and 31.2 psia, respectively.[8]

The combustion chamber is a copper heatsink with a nozzle throat area of 7.148 cm^2 and an exit plane area of 43.80 cm^2. These dimensions provide a nozzle expansion ratio of 6.128. Active cooling of the combustion chamber is provided by enclosing the copper chamber in a stainless steel water jacket and flowing high-velocity water over the outer surface of the chamber. Chamber core temperature is 3348 K.[8] Propellants are pressure-fed into a simple tube-and-annulus-type fuel injector. LOX is injected into the combustion chamber through a tube at a nominal flow of 2.0 lbm/s and GH_2 is injected into the chamber through an annulus at a nominal flow of 0.4 lbm/s. Because of the tube-and-annulus-type injection, the GH_2 effectively sheathes the jet of LOX. Ignition of the combustible mixture is accomplished with a small solid rocket pyrotechnic device. This igniter has a mean burn time of 0.3 s. The igniter burns in the center of the fuel injector through a passageway containing the stinger. The stinger is a cylindrical sleeve with a grooved outer surface. Flame from the igniter flashes through the center of the sleeve while the seeding material flows through the grooves on the outer surface. Dopants are, in this fashion, injected directly into the propellant flowstream and mixed with the propellants during combustion. Uniform mixing of the dopant in the combustion chamber has been assumed for this study.

Dopants are normally injected into the engine in the form of aqueous chemical solutions. These are typically made from either high purity metal salts dissolved in water or pure metal and a low concentration of stabilizing acid in a water solution. Further details on dopant preparation are given later in this section. Baseline firings are also provided by injecting a solution of pure, distilled deionized water into the combustion chamber. GN_2 is used as a pressurant medium for the LOX run tanks, water tanks and the dopant system. GN_2 is also used for purging the engine, the LOX and GH_2 systems, and for actuation of pneumatic motor valves controlling the flow of pressurized fluids. Details and schematics of the DTFT, propellant and pressurants systems, DTFT data acquisition and controls, and dopant injection systems are given in Appendix A.

Spectroscopic Data Acquisition System

The combined hardware and software for the spectroscopic data acquisition system at the DTF is called the Emission Spectroscopy Monitor (ESM). The ESM consists of spectroscopic instrumentation and a control computer that acquires data in real time and archives the data to computer disk. All data presented in this report were obtained with the ESM. Figure 1 shows a diagram of the ESM hardware configuration. The following list summarizes the major hardware components of the system.

1. Collection optics with 2-inch-diameter quartz lens
2. 50-meter fused silica fiber-optic cable
3. 0.32-meter Instruments SA model HR-320 spectrometer
4. 1024-element EG&G model 1412 silicon photodiode detector

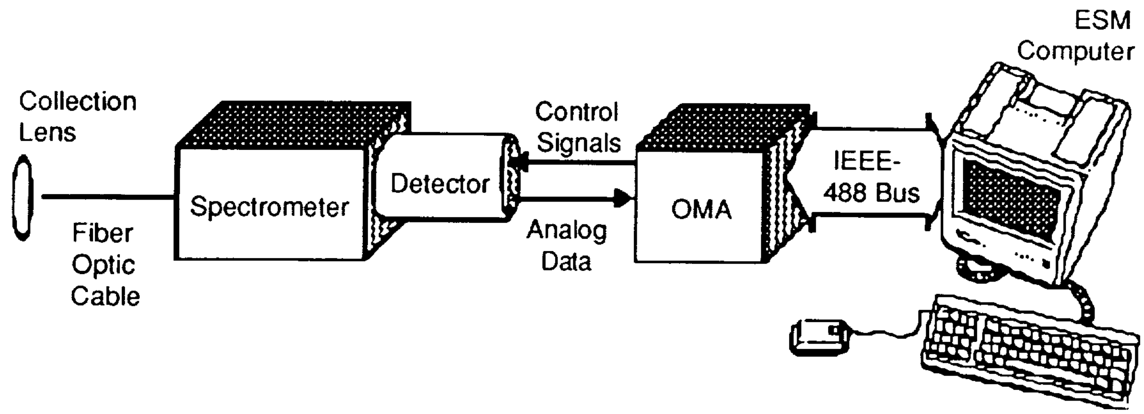

Fig. 1. ESM System Configuration.

5. EG&G model 1460 optical multichannel analyzer (OMA)
6. Macintosh IIfx personal computer with 19-inch monitor

The collection lens is positioned about 96.5 cm from the center line of the DTFT exhaust plume, at a location 13.7 cm downstream of the nozzle exit, with a 0.6-cm diameter field of view (FOV). The lens focuses energy from the first Mach diamond of the DTF plume into the fiber optic cable, which transmits the energy to the spectrometer. Within the spectrometer, polychromatic light is separated into its monochromatic components, which are individually measured by the multi-element photodiode detector. The analog measurement signal of the detector is transmitted to the optical multichannel analyzer (OMA) which controls the operation of the detector, digitizes the incoming data, and transfers it over an IEEE standard 488 bus to a Macintosh IIfx computer.

The Macintosh IIfx serves as the controller and display console. It uses a 32-bit processor and math coprocessor running at 40 MHz. It also includes dedicated processors for disk I/O and serial port I/O that are capable of parallel operation. It is equipped with 8-Mb RAM, a 160-Mb hard drive, a 3.5-in, 1.4-Mb floppy drive, and an IEEE standard 488 I/O board. The ESM sends instructions to the OMA over the 488 bus. These instructions control the operation of the OMA in acquiring plume spectral data, performing low level data processing, and handling data I/O on the 488 bus. During a typical ESM sequence, the OMA acquires a spectral scan from the detector, stores this data in its own RAM, and sends out a copy of the data to the ESM computer. The ESM processes each incoming scan on-line and archives it to computer disk.

The OMA serves as an interface between the ESM computer and the detector. It digitizes the analog signals of the detector, buffers the resulting set of data points in its own RAM, and sets and resets the exposure timing sequence of the detector. It is configured with 4.5 Mb of RAM, a 20-Mb hard drive, and a 5.25-in, 400-kb floppy drive. In addition, it is equipped with a 488 interface port, located on the I/O-A card of its backplane. The OMA is built around a standard VME bus that accepts a variety of VME bus plug-in cards. The I/O-A card is one such card that serves as an I/O interface and allows 488 devices to communicate with the OMA's CPU and access its RAM. The OMA uses about 400 kb of RAM to buffer the data from a typical DTF firing.

The 488 bus interface is the communication channel between the OMA and the ESM. The IEEE 488 standard limits the bus length of the 488 to 20 m. At the DTF, the OMA and detector are located near the plume source and the ESM computer is in the test control center, about 60 m away. For that reason a 488 bus extender is used to interface the OMA and the ESM computer. The model 4889 bus extender, by ICS Electronics Corporation, converts the parallel digital signals of the OMA and ESM into a serial optical signal that is transmitted through a pair of fiber-optic cables. By using one pair of these extenders and one fiber-optic pair, the 488 bus can be extended to 2000 m, and data can be transmitted at 300 kb/s.

The National Instruments 488 I/O board used by the ESM computer supports a maximum transfer rate of 800 kb/s. The average data transfer rate used by the ESM is 4 kb every half second, transmitted in bursts of 50 kb/s. Each data transmission is followed by a period of no transmission, during which time the ESM processes the data it just received. The high transmission

capacity of the bus hardware offers the ability to upgrade the system by interfacing additional diagnostic instruments at some future date.

The model 1412 detector is an unintensified, 1024 element, silicon photodiode array. The individual detector elements continuously integrate the incoming light from the exhaust plume throughout a programmed exposure time. In this way the detector's method of acquiring data has built-in averaging properties. At the end of an exposure, each detector element is read, its value passed to the OMA, and the next exposure begins. Increasing the exposure time improves the signal-to-noise ratio of the acquired data. Decreasing the exposure time improves the transient response (i.e., temporal resolution) of the system. The ESM configures the detector for a 0.5-s exposure time. Since the value from each detector element is digitized by a 14-bit A/D converter, the dynamic range of the detector is 16383 counts. A count level of 16383 indicates that the exposure is too long and the detector saturated. Experience shows that a 0.5-s exposure results in good signal levels while avoiding detector saturation. The detector has a built-in Peltier cooler which is normally set to operate at −30 C. Reducing the detector temperature reduces the leakage current caused by thermally generated carriers. Since the leakage current is integrated along with the signal produced by light from the exhaust plume, reducing it allows for longer exposure times and better use of the available dynamic range.

The spectrometer is a 0.32-m dispersive plane grating spectrometer in a Czerny-Turner configuration. The spectrometer uses a 600-groove/mm plane reflection grating. Grating dispersion determines the spectral window width. Grating dispersion and entrance slit width determine the spectral resolution. Greater grating dispersion gives a narrower window of spectral measurement, but higher resolution. The current 600-groove/mm grating, along with a 25-µ entrance slit, produces a spectral window about 126 nm wide, with a resolution of 0.123 nm/detector element. The window endpoints can be varied by rotating the grating and shifting the image on the detector array. Currently the spectral window covers the region from about 300 to 426 nm.

Calibration and Data Reduction

Calibration of the OMA consists of two major parts: wavelength calibration and spectral radiance calibration. The first step in the calibration procedure is the wavelength calibration. Wavelength calibration consists of determining the wavelength interval measured by each detector element in the array. A multi-element, hollow cathode lamp is currently being used to perform wavelength calibrations of the spectrometer. The model WL36108 lamp, by Imaging and Sensing Technologies, produces atomic emission lines for copper, silver, nickel, iron, and chromium. These lines span nearly the entire 300- to 426-nm region. Since the wavelengths of these lines are precisely known, the wavelengths associated with several detector elements are determined immediately—the ones on which lines are directly imaged. The OMA then performs a cubic fit to determine the wavelengths of the remaining detector elements. In general, the calibration is as accurate as the spectral range per element. Therefore, the wavelength calibration is accurate to within 0.123 nm.

The next step in the calibration process is the spectral radiance calibration. The OMA system is calibrated in the same manner as it is used to make plume measurements—with an overfilled FOV. The model FEL-M standard of spectral irradiance, by Optronics Laboratories, Inc., illuminates a diffuse Lambertian screen. The OMA's collection optics view the radiance of the screen and the OMA records the measured count level. Using the actual irradiance values of the lamp, as supplied by the manufacturer, and the reflectance of the screen, the OMA generates a response function that relates a measured count level to an actual radiometric quantity at the wavelength of each detector element. The units of the response function are counts per radiance unit. For this type of calibration the critical experimental factors are the lamp-to-screen distance and the alignment of the OMA's FOV in the center of the screen.

The OMA converts the measured count level of a plume spectral scan to units of spectral radiance ($W/cm^2 \cdot sr \cdot nm$). The first step is to remove the background level from the measured data. Thermal noise in the silicon detector array produces an offset level that adds to the signal generated by the plume. Ambient light in the measurement region also adds to the plume signal. The OMA takes a spectral measurement just prior to engine ignition. This background scan is taken to represent detector noise and ambient light effects. The background scan is subtracted from all subsequent spectral scans to isolate the contribution of the plume. Once the data have been corrected for background effects, they are converted to the quoted radiometric units by applying the response function described above.

Dopant Preparation

The DTFT is equipped with a dopant injection system which allows dopant solutions to be introduced into the engine's combustion chamber. All dopant solutions are prepared using certified standards traceable to the NIST by the Gas and Materials Analysis Laboratory (GMAL) at SSC. The required concentration by weight of a given element or an alloy in the dopant solution is calculated so that a desired nominal concentration value for that particular element or alloy in the DTFT plume is obtained. The calculation takes into account the mass flow rates for the oxidizer, the fuel, and the dopant. A sample calculation is illustrated in Appendix A.

The dopant solutions for simulated SSME alloys are prepared by mixing appropriate amounts of the constituent elements. The nominal elemental composition of most SSME alloys is given in Ref. 5. These data for Group 1 and Group 2 alloys are reproduced in Tables 3a and 3b. Reference 9 provides the nominal elemental composition of NiCrAlY, the coating material for the High Pressure Oxidizer Turbopump (HPOTP) and High Pressure Fuel Turbopump (HPFTP) turbine blades. The elemental composition of Incoloy 88, used as welding overlay material to protect Inconel 718 weldments,[5] was obtained from the manufacturer, Inco Alloys International. The references for the remaining alloys in Table 3 are provided in Ref. 5. In making the alloy dopant solutions, very minor constituent elements, especially if they are weak emitters in the 300- to 430-nm range, were omitted. Tables 4 and 5 give the nominal desired concentration for spectral testing in the DTFT plume for the elements and the alloys, respectively. All elements and materials except 6061 Aluminum were tested at three concentration levels. Only those Group 1 and Group 2 elements which have identifiable emission spectral lines at concentrations of less than 100 ppm in the DTFT plume are included in Table 4 and the corresponding spectral data presented in this report. Other elements are discussed briefly in Section III. Column 2 of Table 4 shows the desired nominal concentrations of the specie in the plume. Column 3 gives the corresponding calculated values based on actual mass flow rates of the oxidizer, the fuel, and the dopant. Relative detectability of the element in the DTFT exhaust plume is specified in column 4 and the Oxidizer/ Fuel (O/F) mass flow ratio is given in column 5. In columns 2 and 3, the bold numbers refer to concentration values for which the emission spectral data are presented and discussed in this work.

Table 5 gives similar information for simulated alloy species. Few materials/alloys belonging to Group 1 and Group 2 in Table 2 had to be left out. This is discussed in the following section. Spectral data for the 27 SSME simulated alloys are reported in this work. These alloys are listed in Table 5. Any minor constituent elements that were omitted from dopant simulation are indicated in column 2. Estimated nominal concentrations of the dopant in the exhaust plume, assuming uniform distribution, are given in column 3, and corresponding calculated values based on the actual mass flow rates are given in column 4. Bold numbers in columns 3 and 4 identify the material concentrations for which the emission spectral data are presented herein. The O/F ratio is given in column 5. Information on other operating parameters such as mass flow rates and combustion chamber pressure for each dopant firing is also available. For the sake of brevity, this is not included in Tables 4 and 5 since it is not directly relevant to the main purpose of this report.

Table 3a. Nominal Elemental Composition of SSME Alloys in Weight Percentage.

Material \ Element	Ni	Co	Fe	Mn	Cr	Mo	W	Ta	Hf	Ti	Cu	Al	C	Nb	Si	Others
MAR-M 246+Hf	58.0	10.0			9.0	2.5	10.0	1.5	1.7	1.5		5.5	0.1			
Waspaloy	R[a]	13.5	1.0	0.5	19.5	4.2				3.0	0.1[b]	1.2			0.4	0.1[c]
AISI 440C	0.2		80.2	0.5	16.9	0.5					0.1		1.0		0.6	
Haynes 188	22.0	R[a]	3.0[b]	1.3[b]	22.0		14.0						0.1		0.3	0.1[d]
Inconel 718	52.9		18.0	0.2	19.0	3.0				0.8		0.6		5.2	0.2	
Incoloy 903	38.0	15.0	40.0							1.0+		1.0				3.0[e]
Incoloy 625	R[a]	1.0[b]	2.5	0.2	21.5	9.0				0.2		0.2			0.2	3.6[e]
NARloy A											96.0					3.0+[f]
347 CRES	10.5		R[a]	2.0[b]	18.0								0.1[b]		1.0[b]	10xC[g]
A-286	26.0		55.0		15.0	1.3				2.0		0.3				0.3[h]
Incoloy 88	41.0		R[a]	5.5	20.5	2.5				0.4	0.5[b]	0.4	0.1		0.6[b]	
Armco 21-6-9	6.5		R[a]	9.0	20.3										1.0	0.4[b,i]
K-Monel	66.0		0.9			0.7				0.5	29.0	2.7	0.1		0.5	
Rene 41	55.5	11.0			19.0	9.6				3.2		1.5	0.1			

[a]R Indicates remainder [b]Maximum [c]Zr [d]La [e]Nb+Ta [f]Ag [g]Minimum Nb+Ta [h]V [i]N

Table 3b. Nominal Elemental Composition of SSME Alloys in Weight Percentage.

Material \ Element	Ni	Co	Fe	Mn	Cr	Mo	Al	Ti	Cu	C	Si	Sn	V	Mg	Be	Others
Waspaloy X	R[a]	13.5	2.0[b]	0.1[b]	19.5	4.25	1.4	3.0	0.1[b]		0.15[b]					0.05[c]
NiCrAlY	R[a]				16.5		5.5									0.55[d]
Hastelloy X	R[a]	1.5	18.5	1.0[b]	22.0	9.0				0.1	1.0[b]					0.6[e]
Ti-5Al-2.5Sn ELI			0.17				5.0	R[a]				2.5				0.08[f]
Ti-6Al-6V-2Sn			0.6				5.5	R[a]	0.6			2.0	5.5			0.17[f]
Elgiloy	15.5	40.0	R[a]	2.0	20.0	7.0				0.15					0.04	
Inconel X-750	R[a]	0.4	6.5	0.5	15.0		0.6	2.4			0.2					0.85[g]
Inconel 600	R[a]		8.2	0.5	15.5						0.2					
Tens-50 Aluminum							R[a]	0.2			8.0			0.5	0.3	
2024 Aluminum			0.5[b]	0.6	0.1[b]		R[a]	0.15[b]	4.4					1.5		0.25[b,h]
6061 Aluminum			0.7[b]	0.15[b]	0.2		R[a]	0.15[b]	0.28		0.6			1.0		0.25[b,h]
A356 Aluminum			0.2[b]	0.1[b]			R[a]		0.2[b]		7.0			0.35		0.1[b,h]
Hastelloy B-2	65.4	2.5	2.0	1.0	1.0	28.0			0.02		0.1					
Hastelloy B	R[a]	2.5	5.5	1.0	1.0	28.0					1.0		0.4			
Beryllium Copper	0.38								R[a]						2.25	
Nitriding Steel			R[a]	0.55	1.35	0.37	1.12			0.32	0.3[b]					

[a] R Indicates remainder [b]Maximum [c]Zr [d]Y [e]W [f]O [g]Nb [h]Zn

Table 4. SSME-Related Elements Tested at DTFT.

Element	Concentration in Exhaust Plume (ppm by weight)		Detectable at the Lowest Concentration	O/F Ratio
	Nominal*	Calculated*		
Ni	1, 10, **50**	1.0, 9.8, **49.0**	easily	4.97
Fe	1, 10, **50**	1.0, 10.1, **50.5**	easily	5.02
Cr	1, **10**, 50	0.9, **9.3**, 46.3	easily	5.02
Co	1, 10, **50**	1.1, 10.8, **53.8**	yes	4.94
Cu	1, **10**, 50	1.1, **10.7**, 53.4	very easily	5.02
Mn	0.2, 2, 10	0.2, **2.1**, 10.3	extremely easily	5.11
Ca	0.1, 1, **5**	0.1, 0.9, **4.7**	easily	4.96
Al	1, 10, **50**	0.9, 9.2, **46.2**	no	5.02
Ag	1, 10, **50**	1.0, 9.6, **48.1**	extremely easily	4.67
Mg	1, 10, **50**	0.9, 9.2, **46.2**	barely	5.08

* Bolded numbers represent those concentration values for which DTFT plume emission spectral data are presented and discussed in the text and Appendix B.

Table 5. SSME Alloys Tested at DTFT.

Alloy	Minor Constituents Omitted	Concentration in Exhaust Plume (ppm by weight)		O/F Ratio
		Nominal*	Calculated*	
Inconel 718		2, 10, **50**	2.0, 10.2, **50.9**	4.79
Haynes 188	C, La	2, 10, **50**	2.0, 9.9, **49.3**	4.62
MAR-M 246+Hf	C	2, 10, **50**	1.9, 9.7, **48.3**	4.94
Waspaloy X	Si, Zr	2, 10, **50**	1.8, 8.8, **44.0**	4.93
AISI 440C	C	2, 10, **50**	2.0, 10.2, **50.9**	4.79
NARloy-A		2, 10, **50**	1.7, 8.5, **42.6**	5.20
NiCrAlY		2, 10, **50**	1.9, 9.7, **48.3**	4.94
347 CRES	C, Nb, Ta	2, 10, **50**	1.9, 9.4, **46.9**	5.48
A286 CRES		2, 10, **50**	2.0, 9.8, **49.1**	4.78
Inconel 625	Nb, Ta	2, 10, **50**	2.0, 9.9, **49.5**	4.76
Inconel 600		2, 10, **50**	1.9, 9.7, **48.5**	4.61
Incoloy 903		2, 10, **50**	2.0, 9.8, **49.1**	4.67
Inconel X-750		2, 10, **50**	2.1, 10.4, **51.8**	4.45
Armco 21-6-9	N	2, 10, **50**	1.8, 9.2, **45.9**	5.23
K-Monel	C	2, 10, **50**	1.8, 9.0, **45.3**	5.44
Hastelloy B		2, 10, **50**	2.0, 10.0, **50.2**	4.53
Hastelloy B-2		2, 10, **50**	1.9, 9.3, **46.5**	5.57
Hastelloy X	C, W	2, 10, **50**	1.7, 8.7, **43.7**	5.02
Rene 41	C	2, 10, **50**	1.8, 9.0, **44.9**	5.08
Waspaloy	Zr	2, 10, **50**	2.0, 9.8, **49.2**	4.86
Ten-50 Aluminum		2, 20, **100**	2.0, 19.7, **98.6**	5.86
6061 Aluminum	Zn	**100**	**89.4**	5.07
Incoloy 88	C	2, 10, **50**	1.9, 9.7, **48.5**	5.28
Elgiloy	C	2, 10, **50**	2.0, 9.8, **49.2**	5.24
Nitriding Steel	C	2, 10, **50**	2.0, 10.1, **50.4**	5.27
2024 Aluminum	Zn	2, 10, **100**	1.7, 8.7, **87.2**	5.15
A 356 Aluminum	Zn	2, 20, **100**	1.9, 18.6, **92.8**	5.10

* Bolded numbers represent those concentration values for which DTFT plume emission spectral data are presented and discussed in the text and Appendix C.

RESULTS

SSME-Related Elements

The spectral plots for all dopant firings are generated and spectral data analysis performed by using the Igor Graphing and Data Analysis package copyrighted by WaveMetrics. Spectral data for 10 elements which are strong to moderate emitters in the 300- to 426-nm region are presented and discussed first. These elements are Ni, Fe, Cr, Co, Cu, Mn, Ca, Al, Ag, and Mg. The DTFT exhaust plume spectra for these elements, which were taken at the Mach diamond region, are presented along with the corresponding line identification tables in Appendix B. The 0.6-cm diameter FOV, focused precisely 13.7 cm downstream of the nozzle exit, is overfilled by the first DTFT Mach diamond to insure consistency in the radiometric emission source from run to run. Figures B-1 to B-10 show the exhaust plume spectrum in the region of 320 to 426 nm for these elements. Corresponding line identifications are given in Tables B-1 to B-10. The spectral region of 300 to 320 nm is omitted because it is strongly dominated by the (0,0) band of $^2\Sigma$–$^2\Pi$ OH band system. The format is similar for all the figures and it is identical for all the tables in Appendix B. This format is further discussed and utilized in the following discussion relative to the spectral data for nickel in Fig. B-1 and Table B-1.

Figure B-1 shows a DTFT exhaust plume spectrum doped with 50 ppm nickel. The spectral resolution is about 0.25 nm. Because of a rather high number of spectral emission peaks, some of which are in close proximity to each other, the spectral data for 320 to 426 nm is subdivided into two graphs. Figure B-1a covers the region of 320 to 370 nm whereas Fig. B-1b covers the region of 370 to 426 nm. As described in Appendix A, baseline spectra were also obtained for each set of dopant firings by injecting distilled, deionized water into the combustion chamber. Baseline spectra help in isolating contributions from the dopant species. Spectral peaks for 50 ppm Ni are identified and indicated by a sequential number starting with the lowest wavelength Ni peak in Fig. B-1. Spectral lines due to OH which are easily distinguished by a comparison with the baseline spectrum are neither identified in Fig. B-1 nor included in Table B-1. There are many lines from 320 to 350 nm which are fully or partially attributable to OH transitions in the 306-nm band system.[10] Contributing transitions due to the dopant impurity and/or contamination, if any, are also not included. With very few exceptions, the spectra presented here are free from dopant impurity/contamination. Gaseous hydrogen fuel utilized at the DTF has very minute and variable amounts of Na and K. Both of these are extremely strong emitters. Two relatively strong transitions due to potassium are within the spectral range covered. These are located at 404.41 and 404.72 nm, respectively. The potassium line consisting of these two transitions is generally identified if its radiance is significant.

Table B-1 identifies the spectral lines in 50 ppm nickel spectra shown in Fig. B-1. In the table, column 1 refers to the spectral line number in Fig. B-1; column 2 gives the observed wavelength of the peak; and column 3 lists the emitter identified by using spectral literature sources.[11-18] If there is more than one emitter corresponding to an observed line, the stronger contributor is listed first. Column 4 gives the wavelength found in the literature for contributing lines. Whenever possible, line transitions in column 4 are listed in terms of decreasing relative intensity. Lines of weak relative intensity are excluded. Appropriate references for wavelengths are given in column 5. Only four of the most comprehensive of the above-mentioned references for atomic emission lines are mentioned in column 5. These are Ref. numbers 11, 15, 17, and 18. These four references are indicated in column 5 by letter designations based on the last name of the first author or the title of the book for convenience. Reference numbers 11, 15, 17, and 18 are designated by letters A, M, R, and F, respectively, in the line identification tables in Appendix B.

DTFT exhaust plume spectra for 50-ppm iron is presented in Fig. B-2 and Table B-2. The same format as described above for nickel is utilized. Figure B-3 and Table B-3 give the 10 ppm-chromium spectrum. Cobalt spectral data for a 50-ppm concentration level in the plume are provided in Fig. B-4 and Table B-4. Figure B-5 and Table B-5 refer to the DTFT exhaust plume spectrum for copper with an estimated nominal concentration of 10 ppm by weight. The manganese doped spectrum at a 2-ppm concentration level in the plume is shown in Fig. B-6. Three manganese transitions at 403.08, 403.31 and 403.45 nm, respectively, appear as a single line in the spectrum (see Fig. B-6 and Table B-6). Slight contamination due to Ca can be observed in the Mn spectrum as evidenced by the appearance of the 422.67-nm Ca line. Of the ten elements reported herein, manganese is the

strongest emitter. The DTFT exhaust plume spectrum for 5 ppm calcium is presented in Fig. B-7 and Table B-7. The aluminum spectrum at 50-ppm concentration in the plume is given in Fig. B-8 and in corresponding Table B-8. Aluminum is a rather weak emitter in the covered spectral range. Two lines attributed to Al in Fig. B-8, respectively located at 394.48 and 396.08 nm, are only slightly above the background noise level for this spectrum. The emission spectrum for the DTFT exhaust plume doped with 50-ppm silver is given in Fig. B-9 and Table B-9. The 50 ppm magnesium spectrum is shown in Fig. B-10 in the spectral range of 360 to 400 nm. There are no significant Mg emission lines outside of this range within the spectral region covered. For the sake of continuity and in order to show sufficiently detailed structure, only the spectrum for 360 to 400 nm is shown in Fig. B-10. Corresponding line identification information is given in Table B-10. Most of the emission lines in this region are due to MgO or MgOH.[12] In this region there is considerable overlap between the MgO and MgOH bands. MgO(H) in column 3 of Table B-10 indicates that there is uncertainty about the emitting molecular species. Either or both components may be present.

Prominent lines observed at the DTFT in the emission spectra for Ni, Fe, Cr, Co, Cu, Mn, Ca, Al, Ag, and Mg in the spectral range of 320 to 426 nm with spectral resolution of 0.25 nm are given in Table 6. The strongest line in this range is also given for each element. Wavelength values in this table are observed values taken from Tables B-1 to B-10. At this higher resolution, line interference effects are not as significant as were found in the low-resolution DTFT spectra for SSME-related elements.[3]

Of the remaining 13 elements of Group 1 and Group 2 in Table 1, four elements (Au, Be, Hf, and Si) were not tested because they have either no emission lines (in the case of Si) or extremely weak emission lines (in the case of Au, Be and Hf) in the spectral range of 300 to 430 nm.[11,13] In addition, the elements vanadium, tantalum, and niobium occur only as minor constituents (about 5% or less by weight) in one or more alloys[6] and these elements are weak emitters. They are extremely unlikely to be observed in the SSME plume. Beryllium, hafnium, and silicon are also minor constituent elements and gold is a plating material for HPOTP and HPFTP turbine disks. The elements Be, Hf, Si, V, Ta, and Nb are eliminated from further testing at the DTF. Stock solutions for tungsten and zirconium contained 4% and 2% of HF, respectively. This

Table 6. Prominent Spectral Lines for Ten SSME-Related Elements in the Spectral Range of 320 to 426 nm.

Element	Prominent Lines in the High-Resolution DTFT Exhaust Plume Spectra (Wavelength in nm)	Strongest Line (Wavelength in nm)
Nickel	341.51, 345.86, 346.23, 349.34, 351.57, 352.56, 361.98	352.56
Iron	371.99, 373.72, 374.59, 374.96, 382.11, 382.61, 385.69, 386.06, 388.65	386.06
Chromium	357.89, 359.38, 360.62, 425.56	425.56
Cobalt	341.26, 344.99, 345.49, 346.61, 347.47, 350.33, 351.45, 353.06, 357.64, 387.42	387.42
Copper	324.81, 327.43	324.81
Manganese	403.42	403.42
Calcium	422.61	422.61
Aluminum	396.08	396.08
Silver	328.03, 338.25	338.25
Magnesium	370.22, 371.94, 380.82, 383.28, 384.51	370.22

created some problems because hydrofluoric acid tended to react with the fuel injector valve material (304L CRES) introducing iron, chromium, nickel and manganese contamination into the dopant solution and hence into the DTFT exhaust plume. The same problem occurred with titanium whose stock solution matrix had 40% HCl, tin with 60% HCl in its stock solution, and molybdenum with 10% HCl/5% HNO_3 stock solution. The DTFT exhaust plume spectra obtained for Mo, W, Zr, Ti and Sn at 100-ppm concentration levels could not be analyzed adequately because of rather strong presence of Fe, Cr, Ni, and Mn emission lines. However, it is clear that emission spectra of these five elements in the 320- to 426-nm region are quite weak and unlikely to be useful for SSME health monitoring purposes. This point is further discussed in the next section.

Finally, yttrium, which is a constituent of the thermal barrier coating for HPOTP and HPFTP turbine blades, has very strong emission bands in the regions of 465 to 508 nm and 570 to 617 nm.[12] But, these are outside of the current higher-resolution spectral range coverage. Another OMA system at the A-1 Test Stand covers the region from 300 to 800 nm at a spectral resolution of about 1 nm.[1] Low-resolution spectral data for Y, as well as several other elements taken at the DTF, are available in Ref. 19. Yttrium has several atomic emission lines in the spectral range of 300 to 426 nm,[11] but these are weak and could not be observed in the DTFT exhaust plume spectrum even with the yttrium concentration as much as 200 ppm.

SSME Alloys

DTFT exhaust plume spectra for 27 SSME simulated alloys listed in Table 5 are shown in Figs. C-1 to C-27 in Appendix C. Corresponding line identification information is given in Tables C-1 to C-27. The format for the figures and tables is the same as that for elements in Appendix B. The spectral range for all of these figures and tables is 320 nm to 426 nm. As before, the spectral data for 300 to 320 nm, corresponding to the (0,0) OH band, are omitted.

All alloys except Ten-50 Aluminum, 6061 Aluminum, 2024 Aluminum, and A356 Aluminum were tested at a 50-ppm highest nominal concentration in the DTFT exhaust plume. For these four aluminum alloys, maximum concentration of the simulated alloy was increased to 100 ppm because aluminum does not have strong emission lines in the 300- to 426-nm region.

Figure C-1 shows a DTFT exhaust plume spectrum doped with 50-ppm Inconel 718. The spectral resolution is about 0.25 nm. Spectral peaks for 50-ppm Inconel 718 are indicated by a sequential number in Fig. C-1 and the information on line identifications is given in Table C-1. The results for this alloy along with 26 other SSME alloys are summarized in Table 7. Column 1 in Table 7 lists the alloy. Constituent elemental species which have contributed to one or more emission lines of that alloy are given in column 2. The order of elemental species is in decreasing weight percentage obtained from Table 3. The most prominent spectral lines for the purpose of SSME health monitoring are given in column 3. Much detailed spectral information for Inconel 718 is available in Fig. C-1 and Table C-1 as noted in column 4 of Table 7. The reader is referred to Table 7 for finding the figure and table number in Appendix C for each of the remaining 26 SSME alloys whose spectral data are included in this report. Only the significant results/exceptions, if any, are described below.

As expected, weak emitters like Mo do not contribute detectable amounts of radiance even when they are present in an alloy at a high weight percentage level; whereas Mn, one of the strongest emitting metallic species, can be identified in the DTFT exhaust plume spectrum, even when it is present at a 0.1% nominal weight percentage level (e.g., A356 Aluminum and Waspaloy X). This corresponds to a detection sensitivity of 0.05 ppm for Mn in the DTFT exhaust plume. Since the detection sensitivity in the SSME exhaust plume is increased by a factor of 20 or so because of greatly increased source pathlength,[20] Mn could easily be detected in the SSME exhaust plume at concentration levels of 2.5 ppb by weight or about 0.5 ppb based on number of particles in the plume.

The lines at 342.81, 343.21, 345.85, and 347.21 nm are solely or partially due to the (0,1) band of OH in $^2\Sigma$–$^2\Pi$ band system.[12] These line identifications are not made in Tables B-1 to B-10 or C-1 to C-27. Most of the dopant solutions for simulated alloys in this work appear to be free from dopant impurity and/or contamination. One exception is Rene 41 (Fig. C-19 and Table C-19). The DTFT exhaust plume spectrum for Rene 41 suffers from slight contamination from iron. Iron emission lines at 372.07, 373.79, and 374.90 nm can be observed in Fig. C-19.

The wavelength calibration accuracy for all the measured spectra is estimated to be ±0.123 nm. The wavelength calibration for Incoloy 88 (Fig. C-23 and Table C-23), Elgiloy (Fig. C-24 and Table C-24), and Nitriding Steel (Fig. C-25 and Table C-25) is off approximately 0.1 nm with respect to the rest of the spectral data presented in this report.

Alloys whose nominal elemental composition is not significantly different as far as strongly emitting elements (Ni, Fe, Cr, Co, Mn, and Cu) are concerned, are hard to distinguish from each other (e.g., Waspaloy X and Waspaloy, and Hastelloy B-2 and Hastelloy). This is especially true when the concentration of the alloy is very low in the plume. The presence of more than one alloy with basically the same contributing elements introduces additional complicating factors which are briefly discussed in Section IV.

Some Group 1 and Group 2 materials/alloys were either not tested or were tested but not included in this compilation. These materials are: NARloy-Z, MoS_2, $ZrO_2 \cdot 8\%Y_2O_3$, PTFE, Armalon, Ti-5Al-2.5Sn ELI, Ti-6Al-6V-2Sn, Nickel Palladium, and Beryllium Copper. NARloy-Z was not tested because it is not significantly different from NARloy-A from the emission spectroscopy point of view. NARloy-Z has nominal elemental composition[21] of 96.5% Cu, 3% Ag, and 0.5% Zr as compared to NARloy-A composition[5] of 96.0% Cu and slightly more than 3% Ag. Since Zr is a very weak emitter, in essence the emission spectrum for NARloy-Z in the DTFT exhaust plume should be indistinguishable from that of NARloy-A. MoS_2 (just like Mo) has a very weak emission spectrum in the 300- to 426-nm region which could not be observed at up to 100-ppm

Table 7. Summary of Spectral Data Between 320 and 426 nm for SSME Simulated Alloys.

Alloy	Contributing Elemental Species	Most Prominent Lines (Wavelength in nm)	Figure and Table Number for Spectra
Inconel 718	Ni, Cr, Fe, and Mn	341.51, 346.23, 349.34, 351.57, 352.56, 361.98, 386.06, 425.56	C-1
Haynes 188	Co, Ni, Cr, Fe, and Mn	341.51, 345.36, 350.33, 351.57, 352.56, 387.42, 403.42, 425.56	C-2
MAR-M 246+Hf	Ni, Co, and Cr	341.51, 346.23, 349.34, 351.57, 352.56, 361.98, 425.56	C-3
Waspaloy X	Ni, Cr, Co, and Mn	341.49, 346.21, 349.31, 351.54, 352.53, 361.94, 425.43	C-4
AISI 440C	Fe, Cr, Mn, and Ni	371.99, 373.48, 373.72, 374.59, 374.96, 382.48, 386.06, 388.65, 425.56	C-5
NARloy-A	Cu and Ag	324.78, 327.40, 328.03, 338.25	C-6
NiCrAlY	Ni and Cr	341.51, 346.23, 349.34, 351.57, 352.56, 361.98, 425.56	C-7
347 CRES	Fe, Cr, Ni, and Mn	344.10, 352.53, 371.94, 373.67, 374.53, 374.90, 385.62, 388.57, 403.33, 425.43	C-8
A-286	Fe, Ni, and Cr	341.49, 351.54, 352.53, 372.07, 373.67, 374.53, 374.90, 385.99, 425.43	C-9
Inconel 625	Ni, Cr, Fe, Co, and Mn	341.49, 346.21, 349.31, 351.54, 352.53, 361.94, 425.43	C-10
Inconel 600	Ni, Cr, Fe, and Mn	341.49, 345.83, 346.21, 349.31, 351.54, 351.91, 361.94, 425.31	C-11
Incoloy 903	Fe, Ni, and Co	341.49, 346.21, 349.31, 351.54, 352.41, 361.94, 371.94, 373.67, 374.53, 385.99	C-12
Inconel X-750	Ni, Cr, Fe, and Mn	341.49, 345.83, 346.21, 349.31, 351.54, 352.53, 361.94	C-13
Armco 21-6-9	Fe, Cr, Mn, and Ni	371.94, 373.67, 374.53, 374.90, 385.99, 388.57, 403.33, 425.43	C-14
K-Monel	Ni, Cu, and Fe	324.78 327.40, 341.49, 345.83, 346.21, 349.31, 351.54, 352.41, 361.94	C-15
Hastelloy B	Ni, Fe, Co, Mn, and Cr	341.49, 345.83, 346.21, 349.31, 351.54, 352.41, 361.94	C-16
Hastelloy B-2	Ni, Co, Fe, Mn, and Cr	341.49, 345.83, 346.21, 349.31, 351.54, 352.53, 361.94	C-17
Hastelloy X	Ni, Cr, Fe, Co, and Mn	341.49, 346.21, 349.31, 351.54, 352.53, 361.94, 385.99, 425.43	C-18
Rene 41	Ni, Cr, and Co	341.49, 346.21, 349.31, 351.54, 352.53, 361.94, 425.43	C-19
Waspaloy	Ni, Cr, Co, Fe, and Mn	341.51, 345.36, 346.23, 349.34, 351.57, 352.56, 361.98, 425.56	C-20
Tens-50 Aluminum	Al	394.43, 396.16	C-21
6061 Aluminum	Al, Fe, Cu, Cr, and Mn	324.71, 327.32, 371.92, 386.03, 394.43, 396.16, 403.30	C-22
Incoloy 88	Ni, Fe, Cr, Mn, and Cu	341.37, 349.20, 351.43, 352.43, 361.87, 385.91, 403.05, 403.30, 425.36	C-23
Elgiloy	Co, Cr, Fe, Ni, and Mn	341.12, 345.22, 350.19, 351.31, 352.43, 352.92, 387.39, 403.42, 425.48	C-24
Nitriding Steel	Fe, Cr, and Mn	371.92, 373.65, 374.52, 374.89, 382.45, 386.03, 388.63	C-25
2024 Aluminum	Al, Cu, Mg, Mn, Fe, and Cr	324.66, 327.40, 371.94, 385.99, 396.08, 402.96, 403.33	C-26
A356 Aluminum	Al, Cu, Fe, and Mn	324.71, 327.32, 394.43, 396.16, 403.18	C-27

concentration of this lubricant material in the DTFT exhaust plume. Yttria-stabilized Zirconia ($ZrO_2 \cdot 8\%Y_2O_3$) has a very strong emission spectrum due to YO,[13] but it is outside of the covered spectral range and, therefore, not tested.

HPOTP and HPFTP bearing ball cages are made of polytetrafluoroethylene (PTFE) impregnated glass fiber material, Armalon. The exact composition of Armalon is not available, but Se, K, Na, Si and Ca are constituents of the ball retainer material.[5] Only Ca is expected to be useful for monitoring bearing ball cage wear because neither Se nor Si has any emission lines in the region of 300 to 800 nm.[11] On the other hand, very strong atomic emission lines due to Na and K are always present in the SSME exhaust plume. The calcium emission spectrum is presented in Appendix B. Since calcium is currently not a constituent of any other SSME material,[5] and since Armalon is only used for manufacturing HPOTP and HPFTP bearing cages, an ideal situation exists for monitoring a very specific, very critical engine component by means of exhaust plume spectroscopy with a rather high detection sensitivity.[22] As a matter of fact, bearing cage material distress has been correlated with the observation of increased levels of Ca emission in the SSME exhaust plume spectra.[23] PTFE has an extremely low coefficient of friction and it provides additional lubrication to the ball/raceway interface.[24] It is a highly crystalline polymer with a linear molecular structure of repeating $-CF_2$ $-CF_2-$ units. Neither carbon nor fluorine has any emission lines in the 300- to 430-nm region.[11]

The titanium alloys Ti-5Al-2.5Sn ELI and Ti-6Al-6V-2Sn were tested at 50-ppm concentration in the DTFT exhaust plume. As evidenced by the spectra for these two simulated alloys, the dopant solution suffered from slight contamination due to the presence of Fe, Cr, Ni, and Mn because of the higher content of acids in the stock solutions for the elements Ti and Sn. However, no significant emission attributable to the constituents of the above alloys was observed in the 300- to 426-nm region. Neither Nickel Palladium nor Beryllium Copper were tested. Their emission spectrum should essentially resemble the spectrum of Ni and Cu, respectively, because neither Pd nor Be have a strong emission spectrum in the 300- to 430-nm region.

DISCUSSION

The results of this study are being utilized at SSC while monitoring the engine test firings at A-1 Test Stands. Unambiguous identifications of elemental species are easily made. Identification of contributing SSME alloys, however, is very difficult. This can be appreciated by a cursory look at Table 7. Ni, Fe, Cr, Co and Mn are very common emitting species for most of the alloys in Table 7. If more than one of these alloys is present in the SSME exhaust plume, the potential list of contributing alloys must be narrowed by means of failure mode and effect analysis and by correlation with results from other sensors to allow application of suitable algorithms for a qualitative and/or quantitative determination of these alloys. One such algorithm is currently under development at SSC.[25]

The current spectral resolution of 0.25 nm for the SSC OMA-based system is adequate for observing emission spectra of various SSME-related elements and alloys without very significant overlapping and interference effects. However, the current higher-resolution spectral range completely omits or inadequately covers some of the elemental species of interest to plume diagnostics. For some elements, such as Cr, Ca, Al, Ti, and Y, the oxide or hydroxide bands are stronger compared to the atomic emission lines. These are discussed below individually.

Chromium has quite strong lines due to CrO in the H_2-O_2 exhaust plume in the spectral range of 517 to 689 nm.[11,19] However, for Cr, the strong line transition at 425.43 nm is very satisfactory. It is free from interference from other elemental or molecular species that are likely to be present in the SSME exhaust plume. CaOH has a quite strong emission band spectrum at 554, 572, 602, 622, and 644 nm.[13] The strongest emission occurs at 622 and 554 nm. However, for Ca too, the atomic transition at 422.67 nm is more than adequate for health monitoring purposes. It is likely that the detection sensitivity will be slightly better at 622 nm, but interference and overlapping effects are expected to be slightly worse. Aluminum oxide has a band system in the 433- to 541-nm region.[12] But, it is not much stronger than the atomic emission line transition at 396.15 nm.

Titanium oxide has a rather strong emission band spectrum in the 480- to 715-nm region.[13,19] The strongest bandhead occurs at 712.56 nm.[12,19] Other strong bandheads are located at 622.4 and 671.4 nm, but they suffer from interference from very strong emission due to CaOH and Li, respectively. Yttrium Oxide has a very strong band system, $A^2\Sigma$–$X^2\Pi$, which under low resolution appears as two strong lines located at 599 and 615 nm, respectively.[12,13,19] Currently, the A-1 Test Stand is also covered with a wide-band low-resolution OMA system in the spectral range of 300 to 800 nm. While both Ti and Y can, in principle, be detected in the SSME exhaust plume by this low-resolution system, the detection sensitivity is considerably poor compared to the higher-resolution system.

CONCLUDING REMARKS

This report presents the DTFT exhaust plume spectra for SSME Group 1 and Group 2 priority elements and Group 1 and Group 2 priority alloys. Line identification tables are provided. The complete set of wavelength and radiometrically calibrated spectral data at 3 concentration levels (with firing durations of about 3 seconds for each dopant firing) for each element and alloy tested at the DTFT has been archived and stored on optical disk storage media. The spectral data for 6061 Aluminum are available at only one concentration level. These data can be made available to other research and development organizations through NASA upon written request to the SSC Science and Technology Laboratory.

Currently, it is felt that there is insufficient need for obtaining spectral data for Group 3 priority elements and Group 3 priority materials. None of the Group 3 elements (F, Cl, C, Zn, Li, Rh, and Pd), with the exception of lithium, have strong enough emission spectrums in the 300- to 800-nm region. Furthermore, none of the Group 3 elements (again excepting Li) are ever likely to appear in large enough quantities, relatively speaking, to be utilized for the purpose of rocket engine health monitoring. Lithium has a extremely strong atomic line transition at 670.78 nm.[13]

Eight of the seventeen Group 3 priority materials are CRES materials. The DTFT exhaust plume spectra of each CRES material are, in general, indistinguishable from one another. Three Group 3 materials, ZrO_2, WC, and $MoSi_2$, have quite weak emission spectrums in the region of 300 to 800 nm. Also, the polymer materials, Kel-F, Vespel SP-211, Polyurethane, Epoxy Resin, and Buna N cannot be observed in the ultra-violet and visible regions of the spectrum. Only LiF can be detected by monitoring the lithium atomic line at 670.78 nm. It is estimated that Li can be detected in the SSME exhaust plume at 0.05 ppb.

The applicability of this data is very general. For example, these results could be extended to other existing or planned rocket engines and/or turbopumps with appropriate additional testing of materials not already tested. This experimental program has established a knowledge base of spectral line identification information for SSME materials. The line identification, line interference, and spectral characteristics data in this report are critical to developing sensors based on emission or absorption spectroscopy for integrated engine health and condition monitoring.

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APPENDIX A

THE DIAGNOSTIC TESTBED FACILITY: TEST CONFIGURATION FOR LIQUID ROCKET PROPULSION DIAGNOSTICS

THE DIAGNOSTIC TESTBED FACILITY: TEST CONFIGURATION FOR LIQUID ROCKET PROPULSION DIAGNOSTICS

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A-1 Introduction

The Diagnostics Testbed Facility (DTF) at NASA's John C. Stennis Space Center (SSC) in Mississippi was designed to provide a testbed for development of liquid rocket engine exhaust plume diagnostics instrumentation.[1] A 1200-lbf liquid oxygen (LOX)/ gaseous hydrogen (GH_2) thruster is used as the plume source for experimentation and instrument development. Theoretical comparative studies have been performed with aerothermodynamic codes to ensure that the DTF Thruster (DTFT) has been optimized to produce a plume with pressure and temperature conditions as much like the plume of the Space Shuttle Maine Engine (SSME) as possible. The rocket engine is equipped with a plume seeding device which allows liquid seeding materials (dopants) to be injected directly into the combustion chamber.

Operation of the DTFT is controlled by an icon-driven software program using a series of soft switches. Data acquisition is performed using the same software program. A microprocessor-based controller and digital data acquisition system provide accurate mass flow measurements in real time with repeatable engine run conditions.[2] The DTF plays an important role in bridging the gap between technology developers and users. Various government agencies, contractors, and universities use the DTF for advanced instrumentation development and for validation of aerothermodynamic codes. At SSC, the DTF is being used to develop an Engine Diagnostic Console (EDC) for real-time health and condition monitoring of the SSME and to establish an SSME plume and materials database for users within the aerospace community. Training of NASA and contractor personnel in the handling of cryogenic materials and the fundamentals of rocket propulsion testing has been an unforeseen but valuable benefit of this project. The ability of the DTF to provide efficient test operations with quick turnaround times and on-line data analysis makes it uniquely suited for these and other proposed plume diagnostics experiments.

A-2 System Design and Configuration

To fulfill the need for a plume diagnostics testbed for advanced instrumentation development, the DTF had to provide flexible and efficient operations, quick turnaround times between firings, low operational costs, and access to government, industry, and academia.[1] To meet these requirements, the DTF was designed to accommodate a small-scale, low-thrust, pressure-fed rocket engine that could provide the capability to inject small amounts of materials (dopants) into the combustion chamber and thus simulate SSME component wear. A nominal 1200-lbf engine designed at the Marshall Space Flight Center (MSFC) specifically for non-flight research and development projects[2] was selected.

A-2.1 DTF Thruster (DTFT)

The DTFT (Fig. A-1) uses GH_2 and LOX as fuel and oxidizer, respectively. The same design has been used with hydrocarbon fuels at SSC and with hypergolic fuels at the Arnold Engineering Development Center (AEDC).

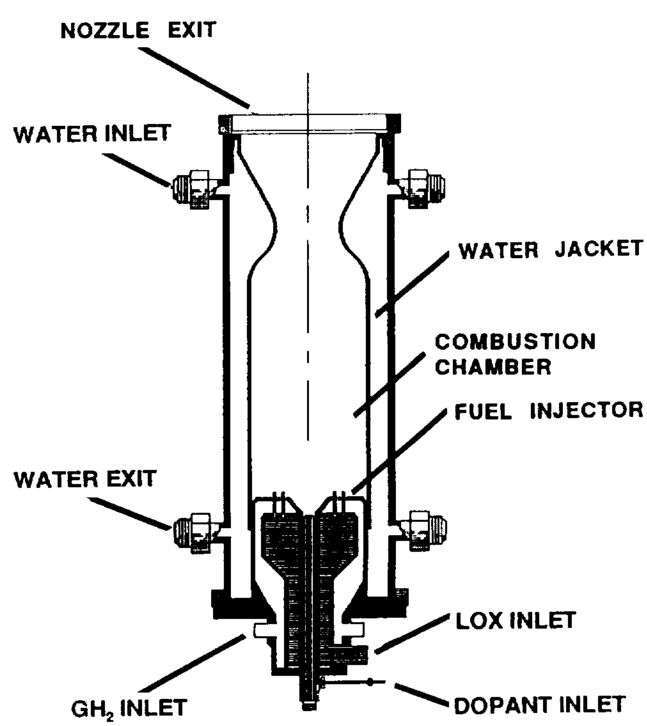

Fig. A-1. DTF Thruster (DTFT).

The DTFT has been optimized to produce a plume with temperature and pressure conditions at the first Mach diamond as much like the SSME plume as possible.[3] Typical operating parameters for plume diagnostics and engine health monitoring experimentation are a combustion chamber pressure of 500 psia and a mixture ratio or oxidizer-to-fuel (O/F) ratio of 5.0.

The combustion chamber is a copper heatsink with a nozzle throat area of 7.148 cm^2 and an exit plane area of 43.80 cm^2. These dimensions provide a nozzle expansion ratio of 6.128. Active cooling of the combustion chamber is provided by enclosing the copper chamber in a stainless steel water jacket and flowing high-velocity water over the outer surface of the chamber. The water jacket is designed for a critical flow of 100 gpm at a supply pressure of 830 psig and a regulated back pressure of 350 psig. Chamber core temperature is 3348 K, but the temperature of the water at the jacket exit seldom exceeds 65 C, even on long-duration firings.

Propellants are pressure-fed into a simple tube-and-annulus-type fuel injector (Fig. A-2). LOX is injected into the combustion chamber through a tube at a nominal pressure of 670 psig and a nominal mass flow rate of 2.0 lbm/s. LOX mass flow is measured by a coriolis-effect true-mass flow meter. GH_2 is injected into the combustion chamber through an annulus at a nominal pressure of 1230 psig and a nominal mass flow rate of 0.4 lbm/s. GH_2 mass flow is calculated by a nozzle method (sonic choke) using upstream temperature and pressure measurements. Because of the tube-and-annulus-type injection, the GH_2 effectively sheathes the jet of LOX. Ignition of the combustible mixture is accomplished with a small solid rocket pyrotechnic device. This igniter has a mean burn time of 0.3 s. An electric match is energized by an electric relay upon a signal from the control computer.

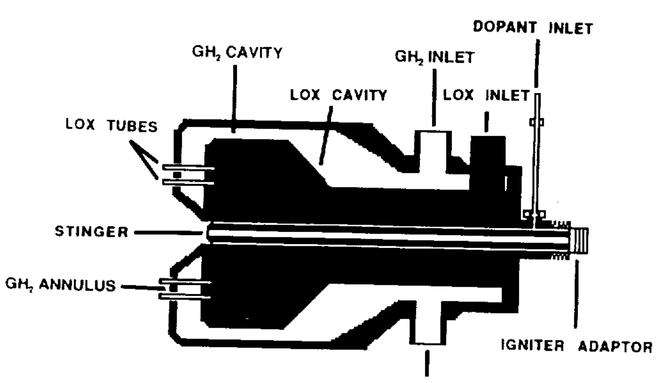

Fig. A-2. DTFT Fuel Injector.

A-2.2 Dopant Injection System

The igniter burns in the center of the fuel injector through a passageway containing the stinger. The stinger is a cylindrical sleeve with a grooved outer surface. The flame from the igniter flashes through the center of the sleeve while the seeding material flows through the grooves on the outer surface. Dopants may then, in this fashion, be injected directly into the propellant flowstream and mixed with the propellants during combustion. A schematic of the dopant injection system is shown in Fig. A-3.

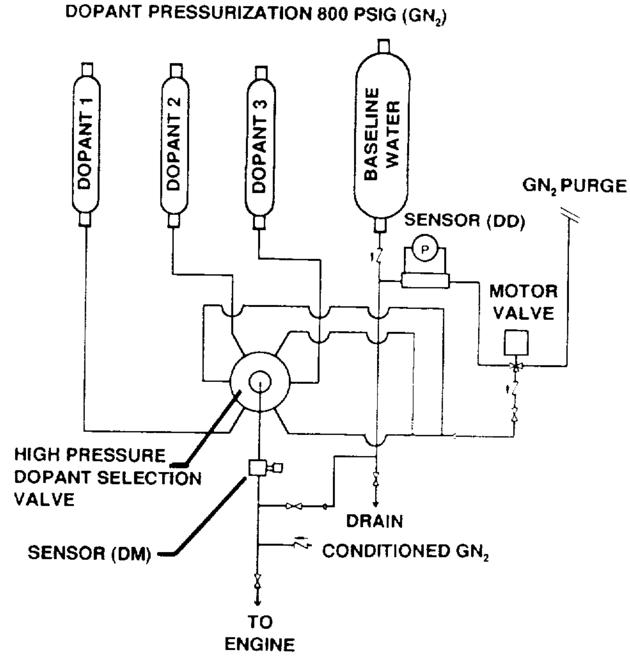

Fig. A-3. DTFT Dopant Injection System.

Dopants are normally injected into the engine in the form of aqueous chemical solutions. These are typically made from National Institute of Standards and Technology (NIST) traceable Atomic Absorption Standard (AAS) solutions containing either high-purity metal salts dissolved in water or pure metal and a low concentration of stabilizing acid in a water solution. Baseline firings are also provided by injecting a solution of pure distilled, deionized water into the combustion chamber. The ability to inject NIST traceable AAS solutions allows the DTF to provide increased accuracy in the dopant injection process. The baseline water is contained in a 2200-ml stainless steel cylinder which is pressurized to 830 psig to inject the baseline water into the engine. The AAS dopant solutions are contained in three 500-ml stainless steel cylinders, each with a

Teflon® (registered trademark of DuPont Co.) inner lining and titanium end fittings. The Teflon® and titanium provide corrosion resistance since some of the dopant solutions are mildly acidic. A high-pressure, acid-resistant tubing made of polyether-etherketone (PEEK) is used to connect the dopant cylinders to a six-inlet, one-common-outlet valve made of titanium. Three lines are run to the valve from the baseline cylinder to provide four injection periods of baseline flow and three periods of dopant flow during the course of one firing. Reconfiguration can allow for up to six separate and different dopant flows to the engine during a single firing. The six-inlet valve is actuated by signals from the facility control computer and switched to different positions based upon a software sequence programmed to meet the experimenters' needs. Ranges in concentration of dopants from 0.1 to 5000 ppm in the plume have been provided by the DTF.

Dopant mass flow measurements are made using a magnetic flow meter device. The internal passageways of this device are made of Teflon® through which two tantalum electrodes protrude into the fluid flow. An electrical current passes between the electrodes whenever a slightly conductive fluid is moving through the passageway. The measurement of this electrical current passed between the electrodes provides a very accurate volumetric flow measurement. The flow rate is nominally 0.02 lbm/s for either the baseline water or dopant solution. Sensor "DM" in Fig. A-3 is the mass flow transducer which measures the dopant mass flow. Distilled water mass flow measurements are made using the differential pressure across a calibrated venturi. This is represented by sensor "DD" in Fig. A-3. The magnetic flow meter (sensor DM) cannot measure the flow of a nonconductive fluid such as distilled water.

A-2.3 Propellants/Pressurant Supply

Propellant supplies are maintained at the DTF. These include a high-pressure (3000 psig) GH_2 line tied into SSC's facility system. This line is constantly maintained so that the DTF has an unlimited supply of gaseous hydrogen. A high-pressure gaseous hydrogen tube bank is used as an accumulator to keep a volume of approximately 17,000 scf of GH_2 at the DTF. It is tied directly into the DTF GH_2 line. A low-pressure vacuum-storage vessel for up to 600 gal of LOX and a companion 100-gal high-pressure (up to 2000 psig) LOX run tank comprise the DTF liquid oxygen storage system. These vessels are refilled as required by the SSC cryogenics operations crew. Two 250-gal high-pressure (830 psig) water storage vessels are used to maintain engine cooling water supply.

Gaseous Nitrogen (GN_2) is supplied to the DTF at 2500 psig through a permanent line connected to the High Pressure Gas Facility (HPGF). GN_2 is used as a pressurant medium for the LOX run tanks, water tanks and the dopant system. GN_2 is also used for purging the engine, the LOX and GH_2 systems, and for actuation of the pneumatic motor valves controlling the flow of pressurized fluids.

A-2.4 Facility and Data Acquisition Control Systems

The control systems at the DTF are designed around a graphical workstation and are all microprocessor controlled. Graphical interface, icon-driven software is used to design virtual instruments which simulate actual hardware instruments on the computer monitor. A customized program on the control computer provides a series of soft switches which are activated by clicking a mouse on the computer monitor. This signal is then transmitted over a four-conductor (two twisted pair) serial cable to an external microprocessor (slaved to the control computer). A series of optical isolation relays transmit signals from the slave computer to the solenoid valves that control the flow of pressurants and propellants on the test pad. Once the systems are readied for a firing, activation of a single switch initiates the firing sequence. The computer-controlled sequence opens propellant and pressurant valves, controls the flow of dopants, and triggers the igniter. The sequence provides DTF operational repeatability to within 1/8 s. This repeatability is necessary for successful plume diagnostics experimentation. The front panel display for a typical firing sequence is shown in Fig. A-4 and the timing sequence for a typical 30-s firing is shown in Fig. A-5.

Data acquisition is accomplished with the same computer software. A separate slave microprocessor performs analog-to-digital conversion of 32 different pressure, temperature, and mass flow transducers on the test pad. These data are displayed in real time on the control computer's monitor and are used to check against operational redlines. Should any of the measured parameters exceed set limits, the control computer will automatically terminate the firing. All of the measured data are recorded on hard disk for later analysis.

The control and data acquisition systems are designed with flexibility in mind. Programs may be

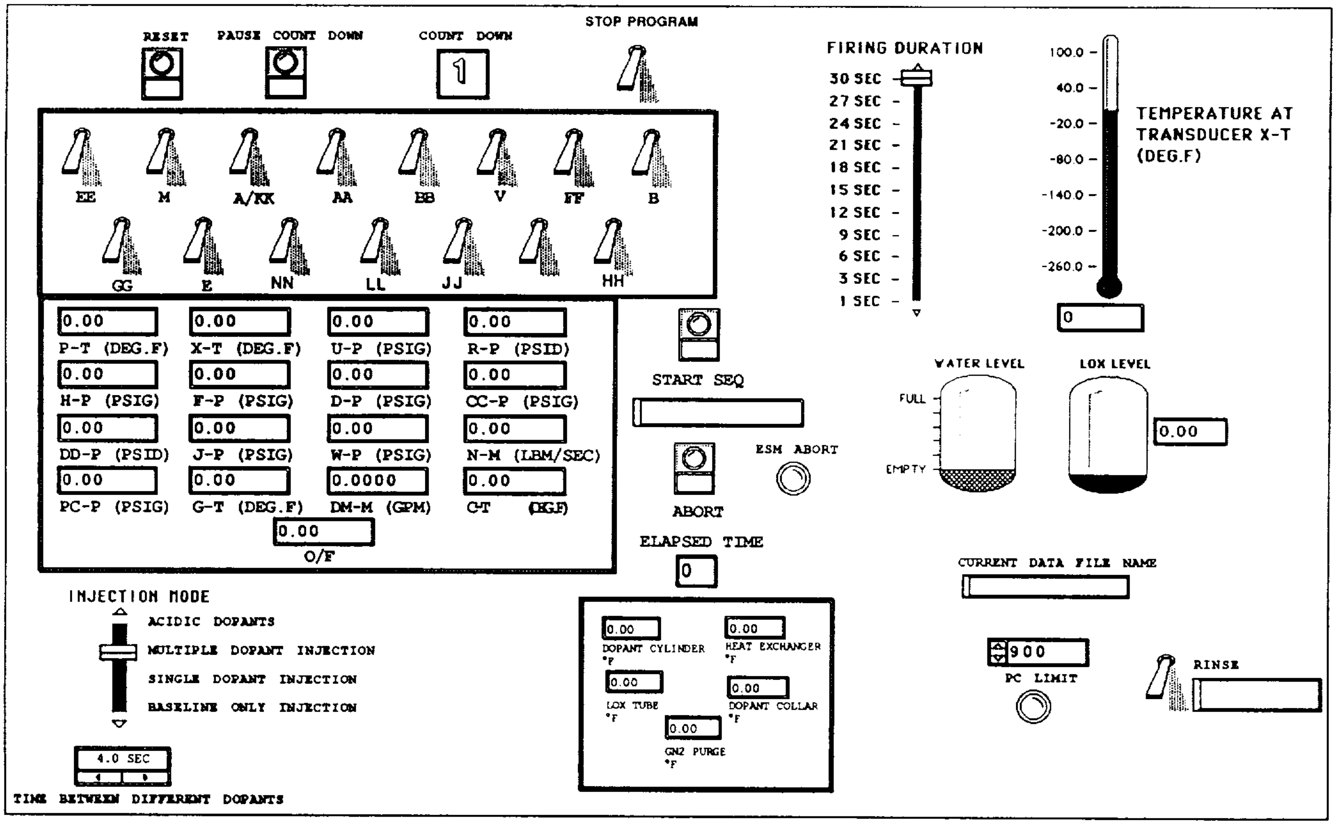

Fig. A-4. DTF Control Computer, Front Panel Firing Sequence.

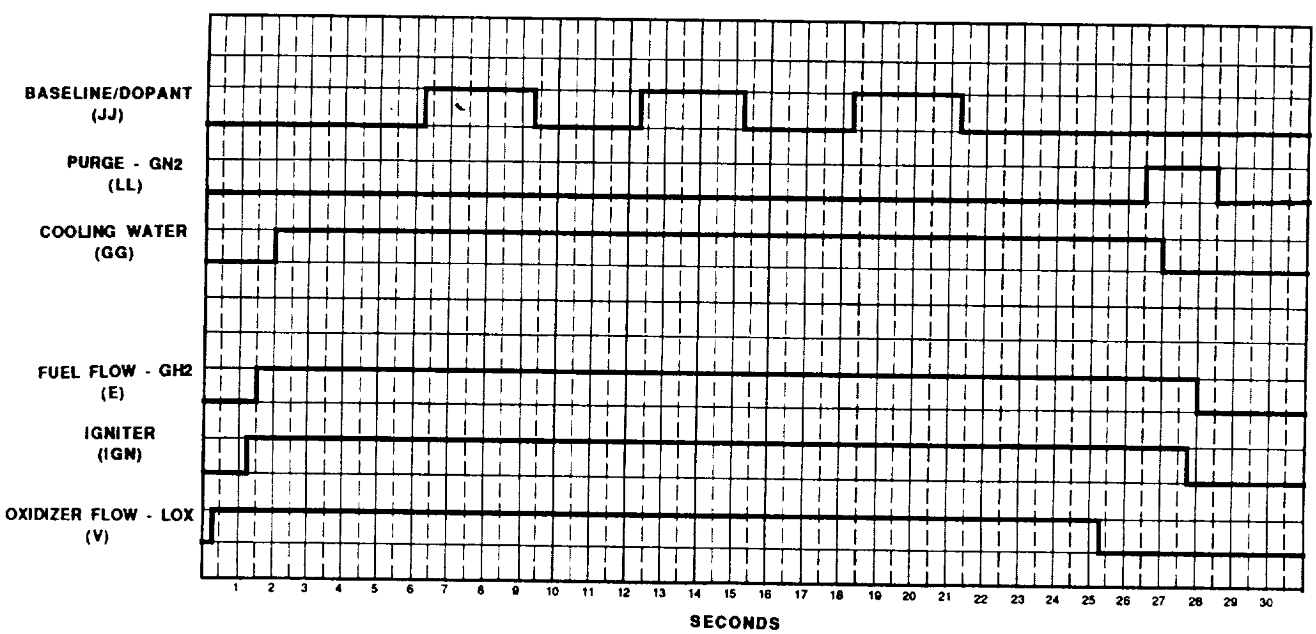

Fig. A-5. Typical 30-Second Firing Sequence for DTF Thruster.

changed by controls on the screen to set different firing durations and the control sequence can be easily adapted in minutes to conform to different experimental requirements. Analog representations of measurement devices (e.g., thermometers) can be readily monitored to give the crew the capability to alter the experimental setup. Real-time data displays and built-in manual abort sequences allow for additional, specialized control of the experimental firings.

A-3 Dopant Concentration Determination and Quality Assurance

Nominal conditions for a given test are obtained by proper regulation of propellant and dopant mass flows. For a given test, dopant solutions are prepared ahead of time to provide the user with the desired species concentration in the exhaust plume. Preparation of the solution is based on anticipated mass flow of propellants and dopant. Species concentrations in the exhaust plume are regulated by preparation of dopant solutions to deliver the desired species mass flow. Examples presented below describe the methods used to calculate the required concentration of dopant solution and actual species concentration in the exhaust plume. Figure A-6 shows actual data from DTFT Test 129D which are used in one of the examples.

Average mass flows from several previous DTFT tests are used to calculate the species mass flow. This simplifies the dopant preparation process and minimizes mass flow variations resulting from changing ambient conditions. Nominal mass flow rates are used in the following example to prepare a dopant solution for 10-ppm Chromium (Cr) in the exhaust plume. In this example, dopant mass flow is 0.02 lbm/s, LOX mass flow is 2.00 lbm/s and GH_2 mass flow is 0.40 lbm/s, which results in an average total mass flow of 2.42 lbm/s. For these flow rates the actual mass fraction of dopant (MF_{dopant}) is:

$$MF_{dopant} = \text{Dopant Mass Flow} / (\text{Total Mass Flow})$$
$$= 0.02 \text{ lbm/s} / (2.420 \text{ lbm/s})$$
$$= 0.00826$$

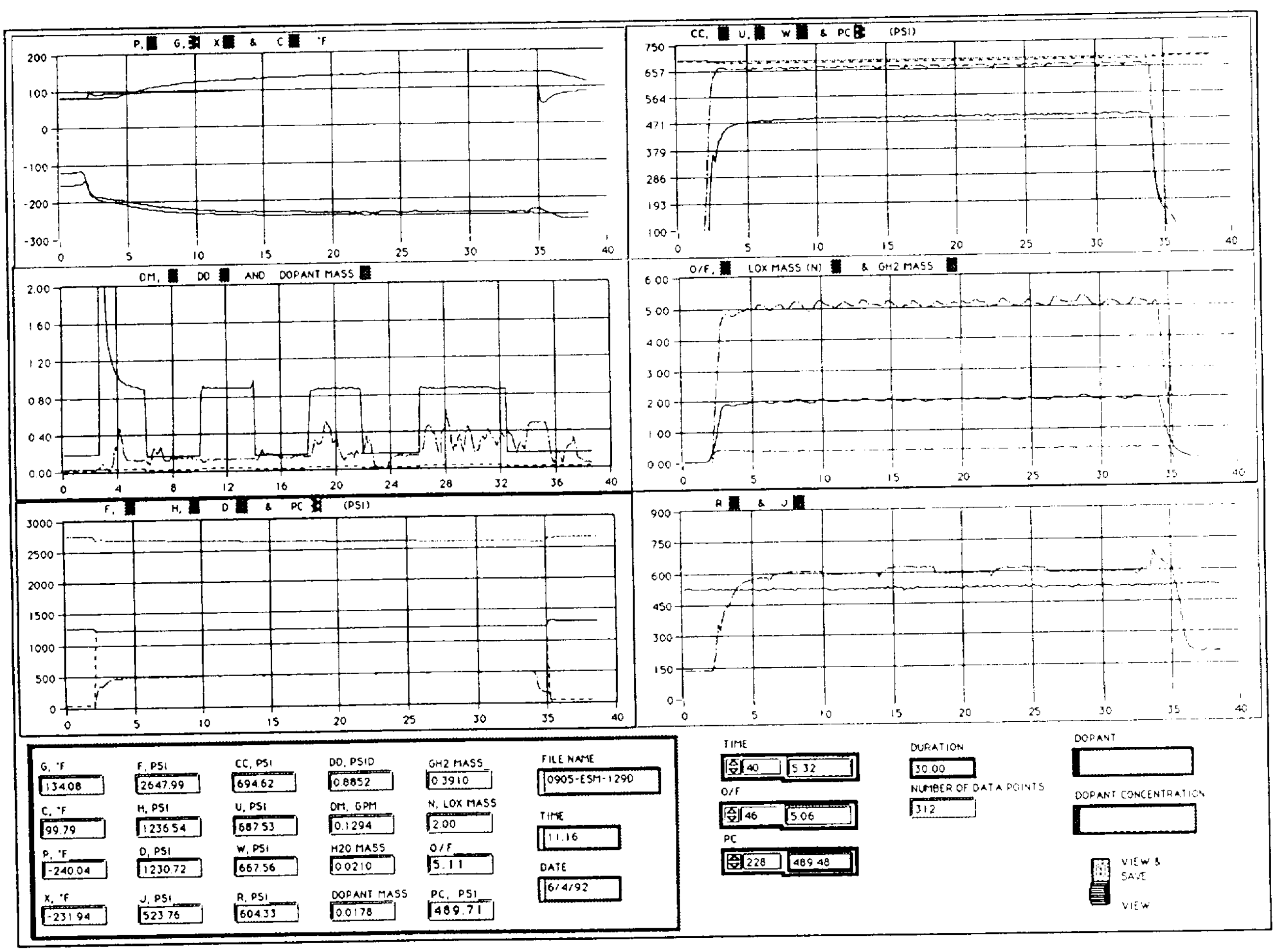

Fig. A-6. Test Results—DTF Test Series 129D.

Dopant solutions are prepared in the SSC Gas and Materials Analysis Laboratory (GMAL) from NIST traceable AAS standards. Solutions with concentrations ranging from 2500 to 50,000 ppm are normally kept in stock. To obtain the required concentration for a dopant solution, the desired species concentration in the exhaust plume is divided by the anticipated dopant mass fraction. For a 10.0-ppm Cr specie concentration in the exhaust plume ($Specie_{Plume}$) the required Cr dopant concentration ($Dopant_{Conc}$) is:

$$\begin{aligned} Dopant_{Conc} &= Specie_{Plume}\,(\text{Desired}) / MF_{dopant} \\ &= 10.0 \text{ ppm Cr} / 0.00826 \\ &= 1210 \text{ ppm Cr} \end{aligned}$$

To prepare dopant solutions, the GMAL maintains a series of calibrated instruments, including several motorized pipets, to measure and dispense precise quantities of distilled water and AAS solutions. This method of transferring solutions provides an accuracy of 1/100 ml. A simple proportion is used to determine the volume of AAS standard solution in a desired volume to get the required concentration of the dopant solution. After each test, a sample of the remaining dopant solution is recovered and retained at the GMAL for quantitative chemical analysis should questions concerning dopant integrity arise.

Species concentration in the exhaust plume ($Specie_{Plume}$) is calculated using actual mass flow measurements and the pre-mixed dopant solution concentrations. Mass flow data from DTFT test 129D (Fig. A-6) and the above example of the Cr dopant are used below to illustrate the calculation of Cr specie concentration in the exhaust plume. In this example, Cr dopant mass flow is 0.0178 lbm/s, LOX mass flow is 2.00 lbm/s and GH_2 mass flow is 0.3910 lbm/s, which results in a total mass flow of 2.4088 lbm/s. The Cr concentration in the exhaust plume is:

$$\begin{aligned} Specie_{Plume} &= MF_{dopant}\,(\text{actual}) \times Dopant_{Conc} \\ &= (0.0178 \text{ lbm/s} / 2.4088 \text{ lbm/s}) \\ &\quad \times 1210 \text{ ppm Cr} \\ &= 8.94 \text{ ppm Cr} \end{aligned}$$

For multi-element solutions, individual mass fractions are calculated in the same manner. For instance, a solution to simulate Inconel 718 would contain 52.9% nickel, by weight, 19% chromium, and 18% iron, with the balance being made up of several other constituent elements in small amounts. A desired solution of 10-ppm Inconel 718 could then be simulated by making a combined solution of 5.29-ppm Ni, 1.9-ppm Cr and 1.8-ppm Fe and, with appropriate proportions of the other constituent elements.

A-4 DTF Operations

A crew of four is required to operate the DTF. Procedures have been optimized to provide a minimum turnaround time between firings. The four-man crew has performed as many as 18 firings in one day with as little as 10 minutes between firings. By making use of the graphical workstations and the icon-driven software for data analysis, the operations crew can provide a complete report on a given firing within 5 minutes of firing completion. Because the icon-driven graphical programming language is used extensively in data analysis and can instantly provide test results, the experimenter is provided with flexibility and has any number of options presented for each firing. These options can include long periods of time for instrument recalibration or for more detailed data analysis. Rapid succession firings may not always be desirable or appropriate. Adaptability of the facility and crew allows continuous consideration of the experimenter's needs.

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APPENDIX B

SSME-RELATED ELEMENTS: DTFT EXHAUST PLUME SPECTRA AND LINE IDENTIFICATION TABLES

SSME-RELATED ELEMENTS: DTFT EXHAUST PLUME SPECTRA AND LINE IDENTIFICATION TABLES

List of Figures and Tables

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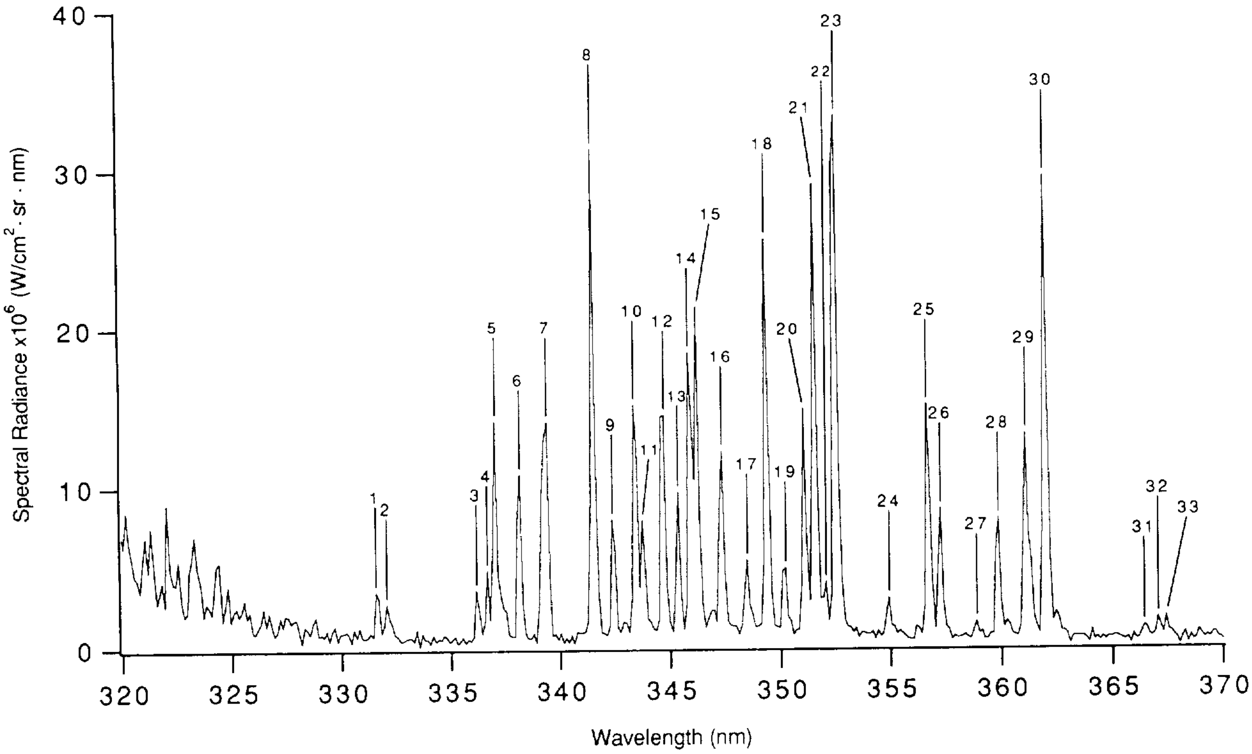

Fig. B-1a. Ni, 50 ppm; DTFT Plume Spectrum, 320 to 370 nm.

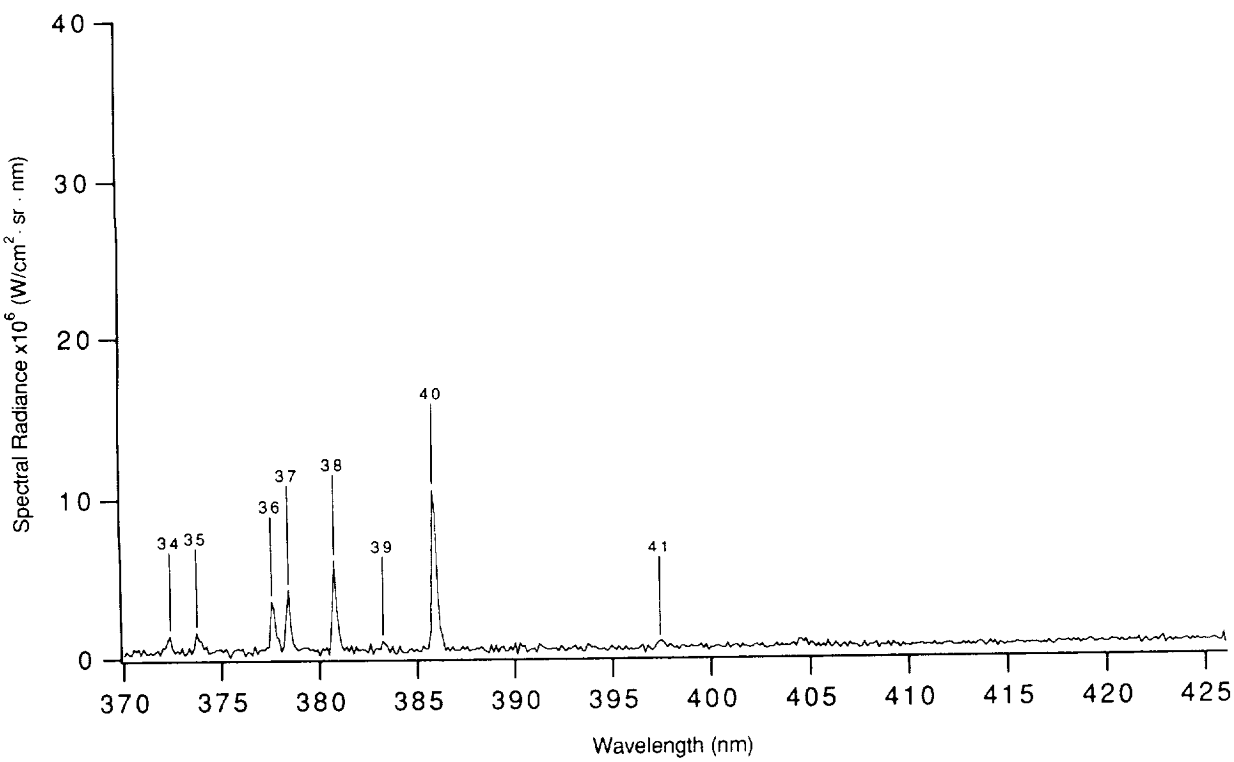

Fig. B-1b. Ni, 50 ppm; DTFT Plume Spectrum, 370 to 426 nm.

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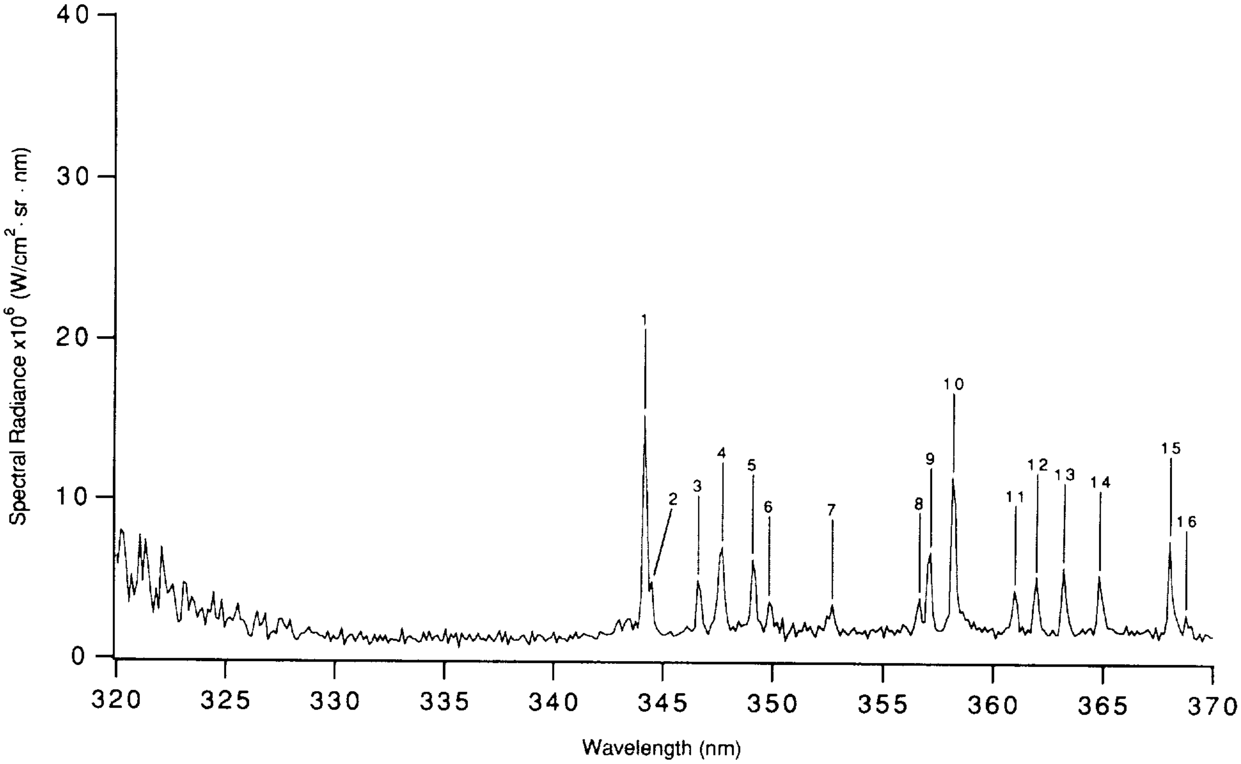

Fig. B-2a. Fe, 50 ppm; DTFT Plume Spectrum, 320 to 370 nm.

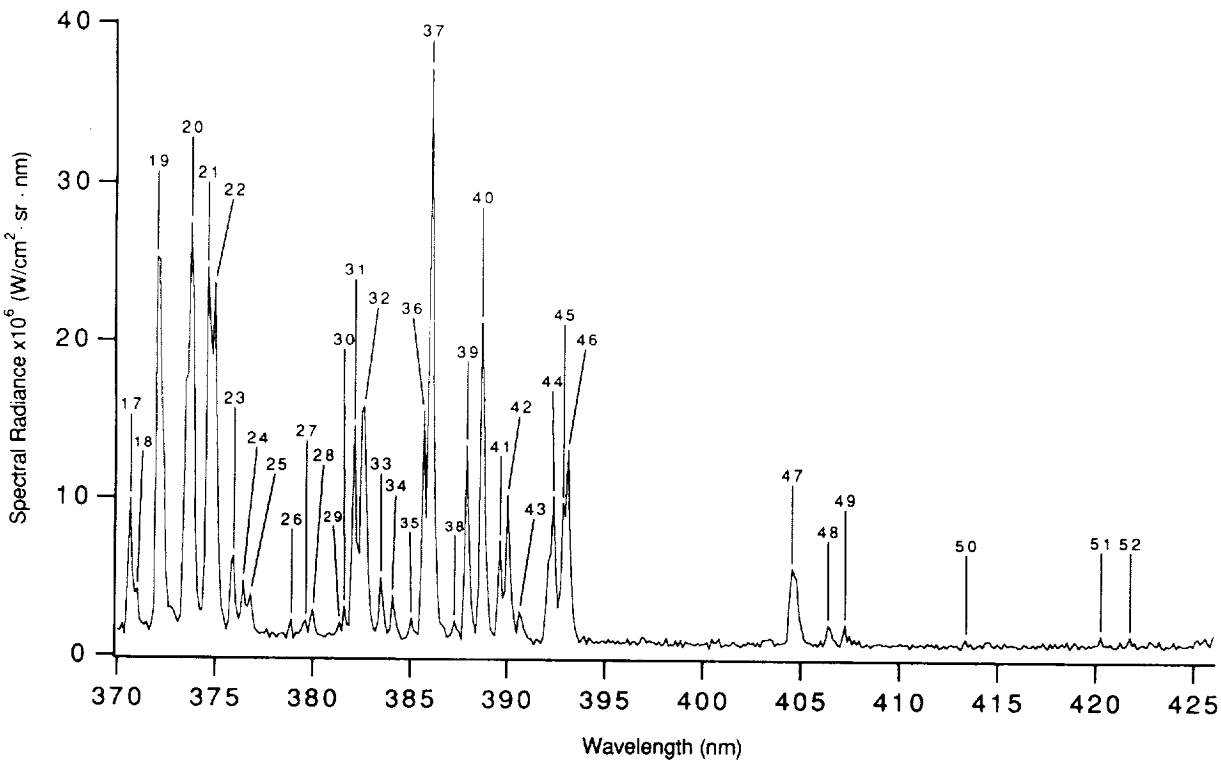

Fig. B-2b. Fe, 50 ppm; DTFT Plume Spectrum, 370 to 426 nm.

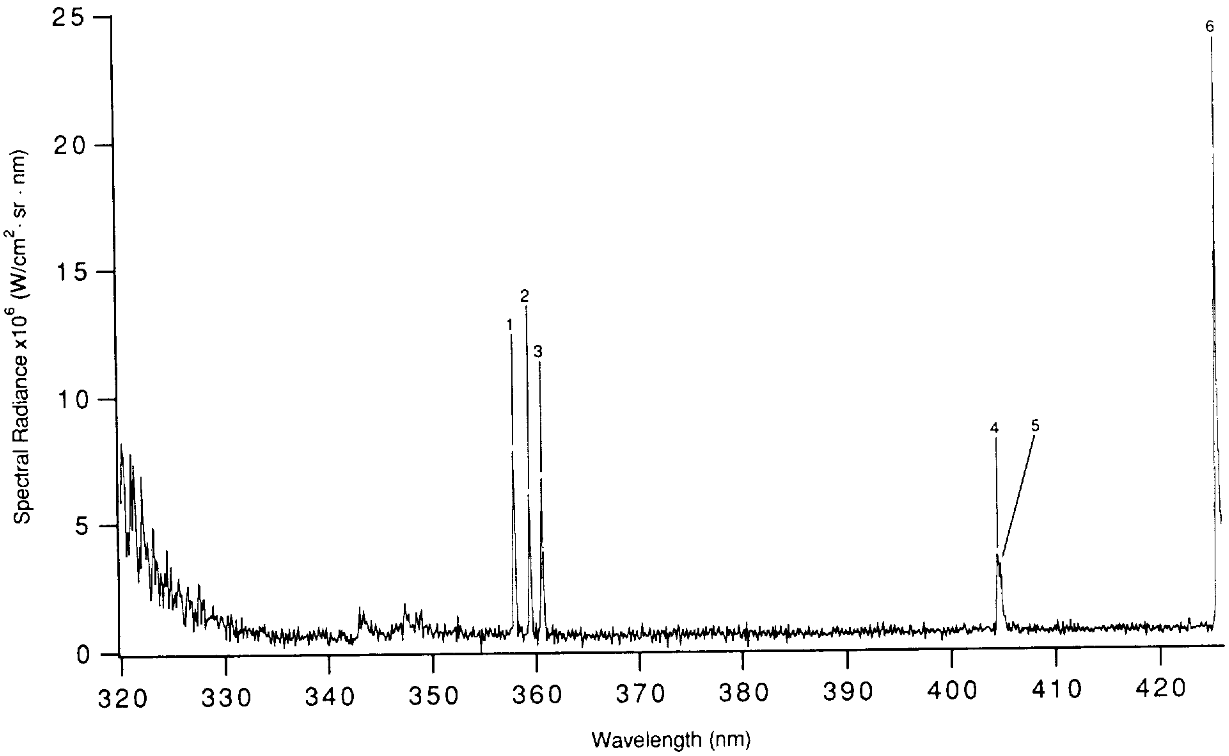

Fig. B-3. Cr, 10 ppm; DTFT Plume Spectrum, 320 to 426 nm.

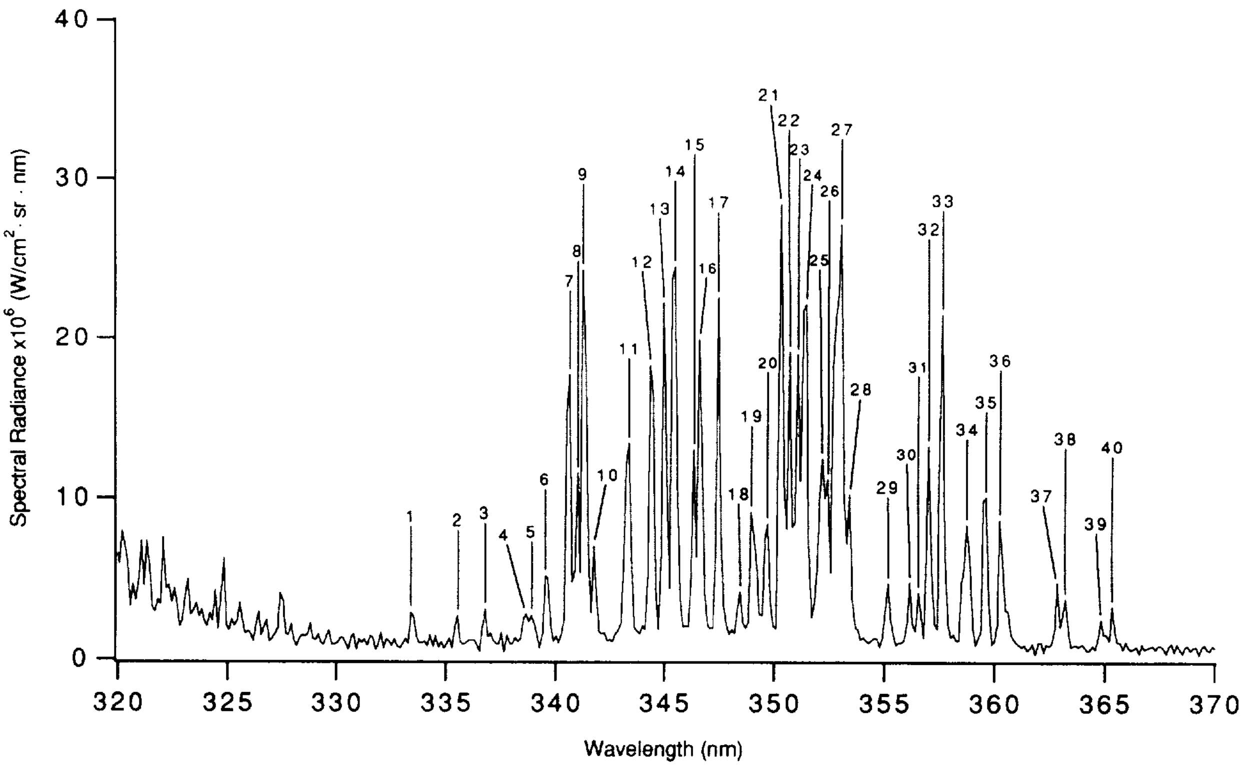

Fig. B-4a. Co, 50 ppm; DTFT Plume Spectrum, 320 to 370 nm.

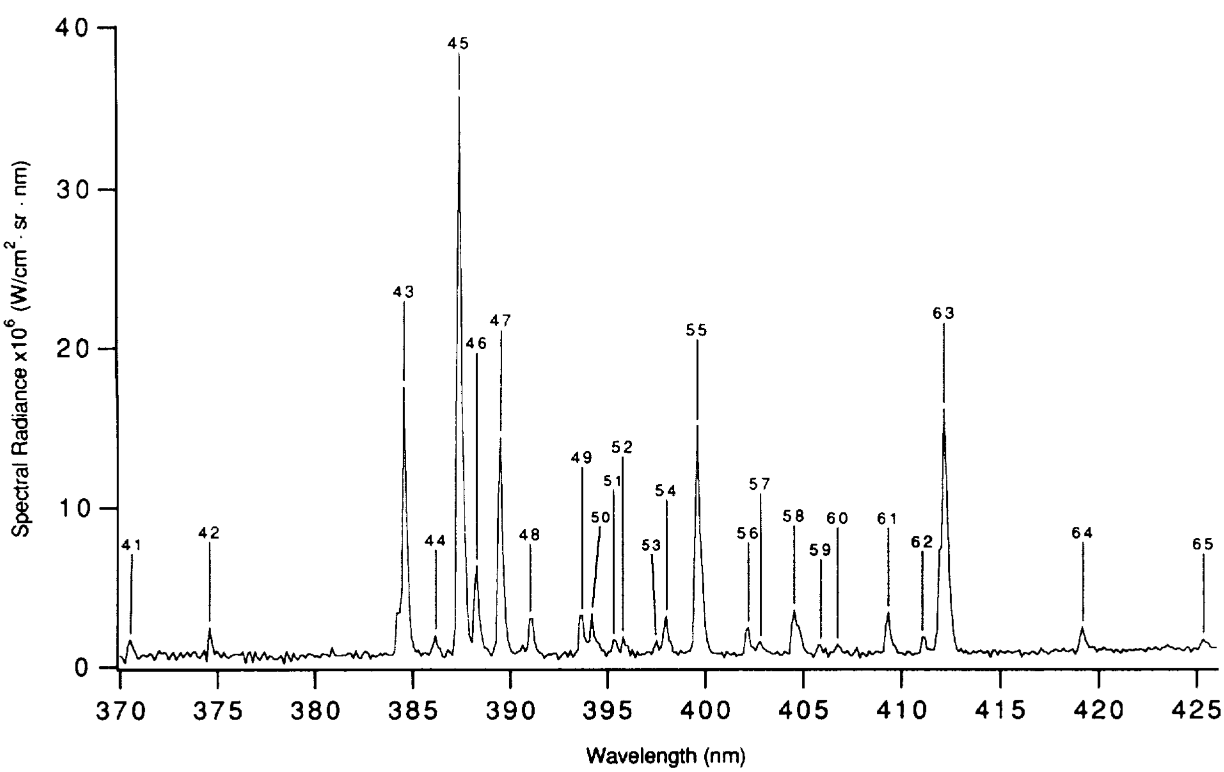

Fig. B-4b. Co, 50 ppm; DTFT Plume Spectrum, 370 to 426 nm.

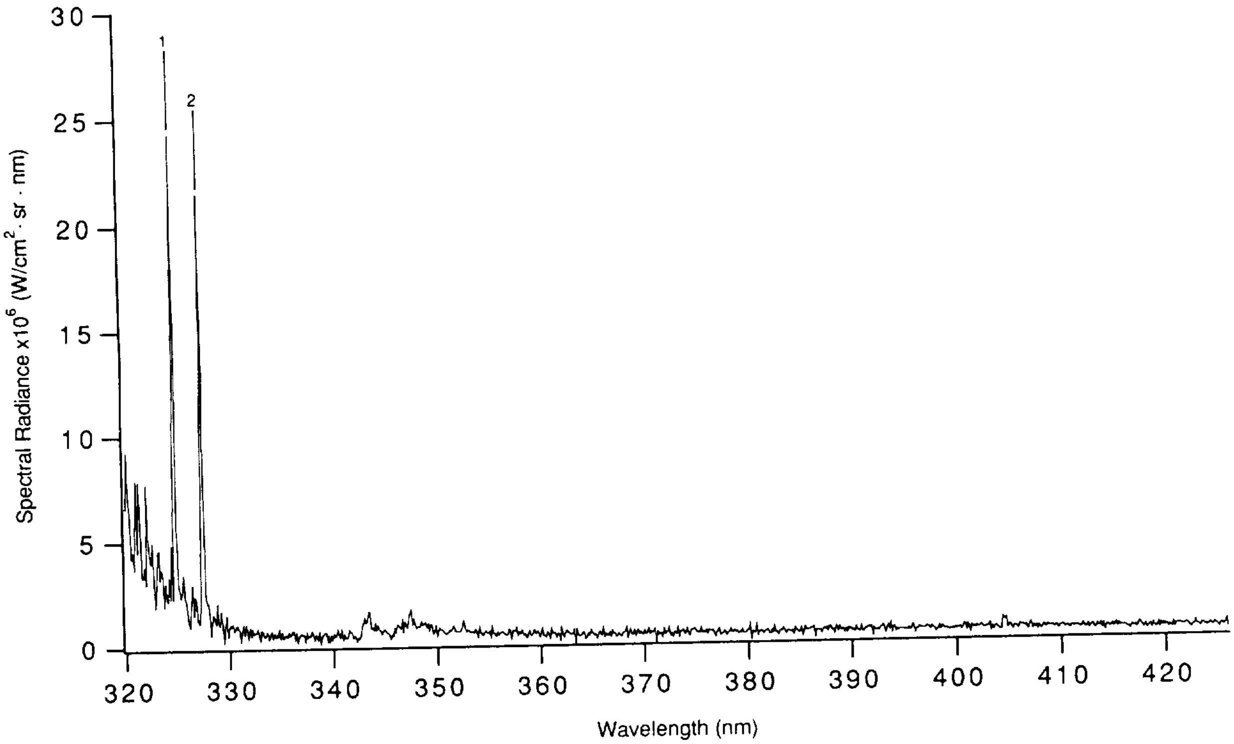

Fig. B-5. Cu, 10 ppm; DTFT Plume Spectrum, 320 to 426 nm.

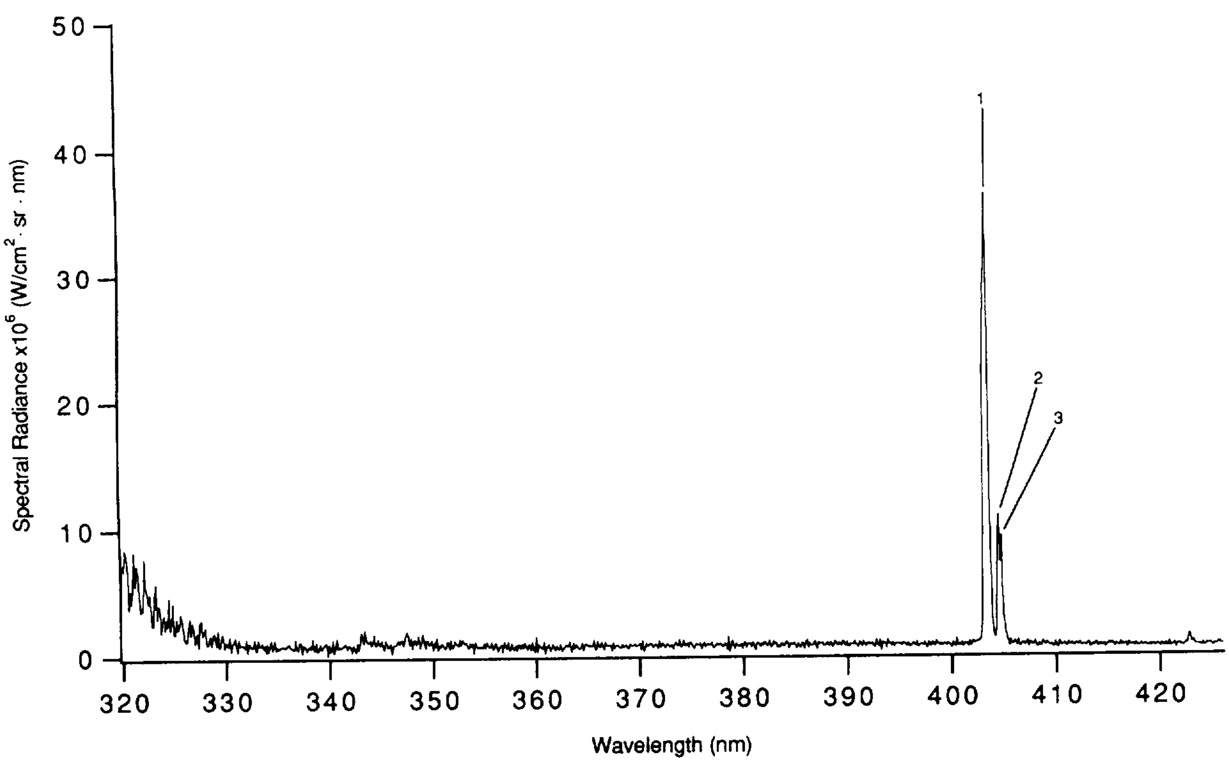

Fig. B-6. Mn, 2 ppm; DTFT Plume Spectrum, 320 to 426 nm.

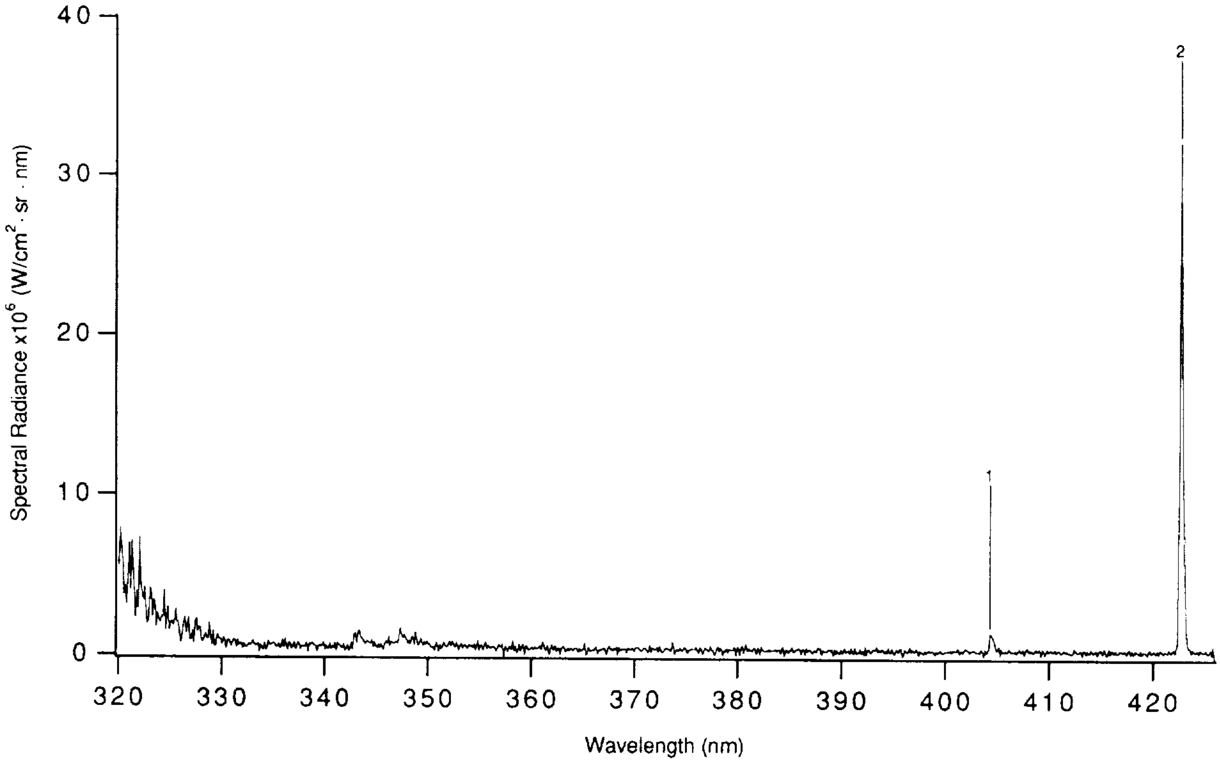

Fig. B-7. Ca, 5 ppm; DTFT Plume Spectrum, 320 to 426 nm.

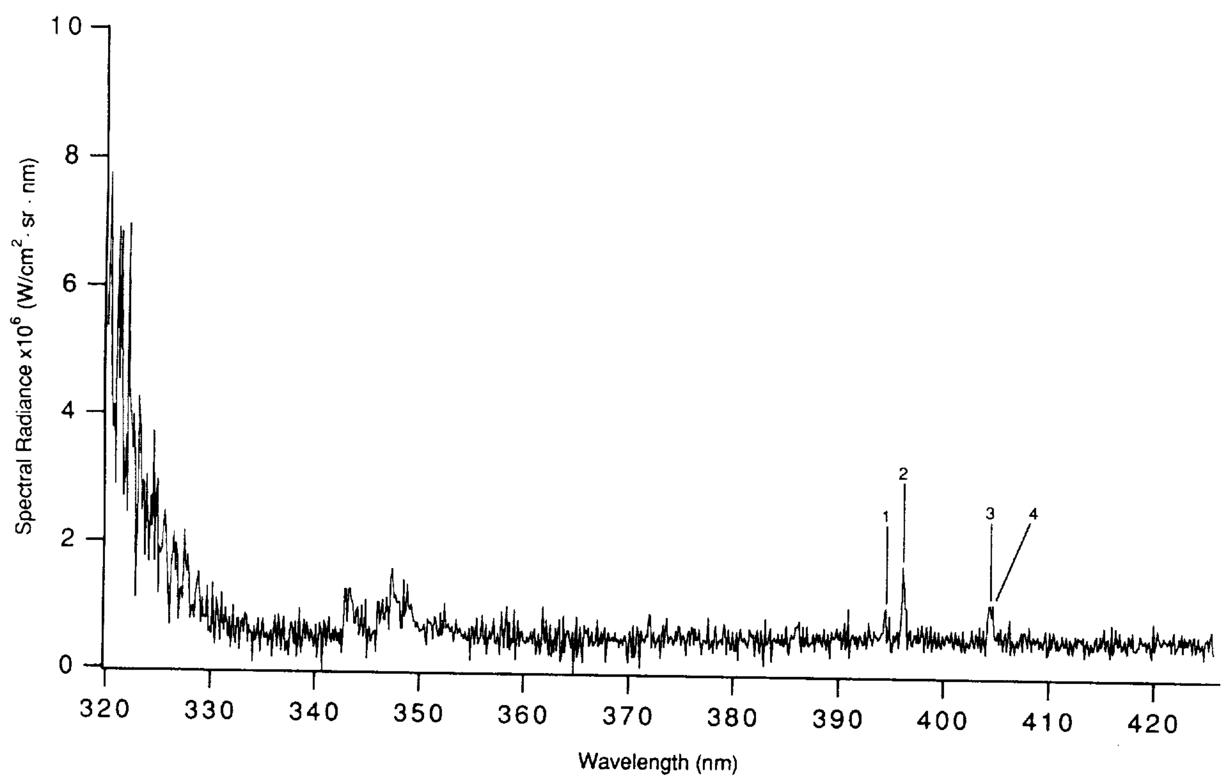

Fig. B-8. Al, 50 ppm; DTFT Plume Spectrum, 320 to 426 nm.

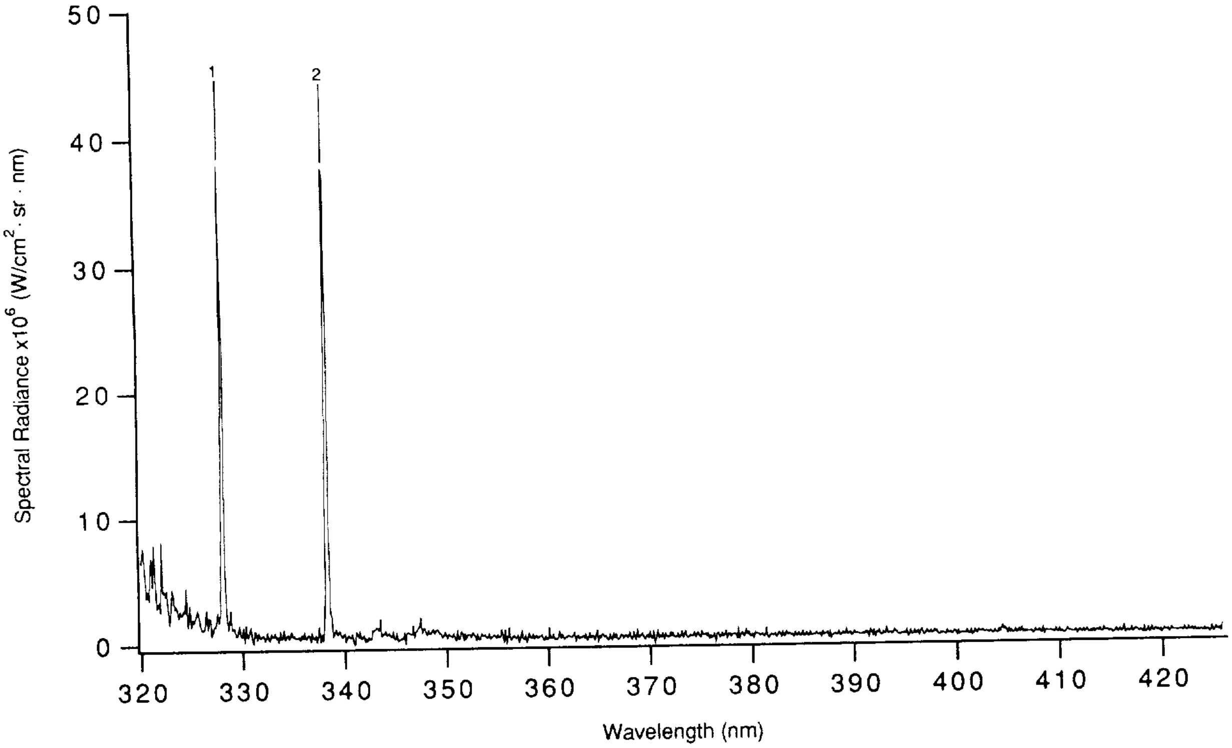

Fig. B-9. Ag, 50 ppm; DTFT Plume Spectrum, 320 to 426 nm.

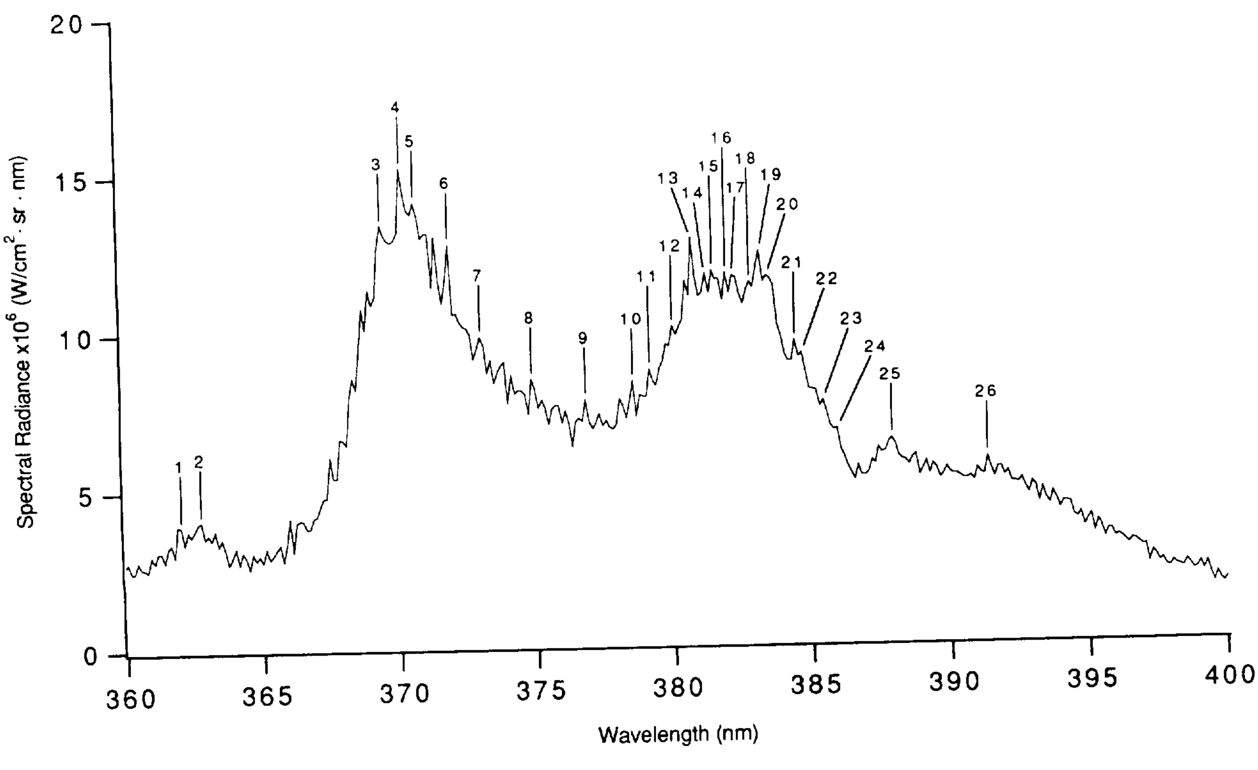

Fig. B-10. Mg, 50 ppm; DTFT Plume Spectrum, 360 to 400 nm.

Table B-1. Spectral Lines of DTFT Exhaust Plume Doped with 50 ppm Ni.

Peak No.	Wavelength (in nm)	Emitter	Contributing Lines (Wavelength in nm)	References
1	331.55	Ni	331.57	A, F, M, R
2	332.05	Ni	332.03, 332.23	A, M, R
3	336.16	Ni	336.16	A, F, M, R
4	336.66	Ni	336.62, 336.58	A, F, M, R
5	337.03	Ni	336.96, 337.20	A, M, R
6	338.15	Ni	338.06, 338.09	A, F, M, R
7	339.39	Ni	339.30, 339.11	A, F, M, R
8	341.51	Ni	341.48, 341.39, 341.35	A, M, R
9	342.38	Ni	342.37	A, F, M, R
10	343.38	Ni	343.36	A, F, M, R
11	343.75	Ni	343.73	A, F, M, R
12	344.74	Ni	344.63	A, F, M, R
13	345.36	Ni	345.29	A, F, M, R
14	345.86	Ni	345.85	A, F, M, R
15	346.23	Ni	346.17	A, F, M, R
16	347.35	Ni	347.25	A, F, M, R
17	348.47	Ni	348.38, 348.59	A, F, M, R
18	349.34	Ni	349.30	A, F, M, R
19	350.20	Ni	350.09	A, F, M, R
20	351.07	Ni	351.03	A, F, M, R
21	351.57	Ni	351.51	A, F, M, R
22	352.07	Ni	351.98	A, F, M, R
23	352.56	Ni	352.45	A, F, M, R
24	354.92	Ni	354.82	A, F, M, R
25	356.65	Ni	356.64	A, F, M, R
26	357.27	Ni	357.19	A, F, M, R
27	358.88	Ni	358.79	A, M, R
28	359.87	Ni	359.77	A, F, M, R
29	361.11	Ni	361.05, 361.27	A, F, M, R
30	361.98	Ni	361.94	A, F, M, R
31	366.43	Ni	366.41	A, M, R
32	367.05	Ni	367.04	A, M, R
33	367.42	Ni	367.41	A, M, R

Table B-1. Spectral Lines of DTFT Exhaust Plume Doped with 50 ppm Ni (continued).

Peak No.	Wavelength (in nm)	Emitter	Contributing Lines (Wavelength in nm)	References
34	372.36	Ni	372.25	A, M, R
35	373.72	Ni	373.68	A, M, R
36	377.55	Ni	377.56	A, F, M, R
37	378.41	Ni	378.35	A, F, M, R
38	380.76	Ni	380.71	A, F, M, R
39	383.22	Ni	383.17	A, M, R
40	385.81	Ni	385.83	A, F, M, R
41	397.39	Ni	397.36	A, M, R

Table B-2. Spectral Lines of DTFT Exhaust Plume Doped with 50 ppm Fe.

Peak No.	Wavelength (in nm)	Emitter	Contributing Lines (Wavelength in nm)	References
1	344.12	Fe	344.06, 344.10	A, F, M, R
2	344.49	Fe	344.39	A, F, M, R
3	346.61	Fe	346.59	A, F, M, R
4	347.72	Fe	347.55, 347.67, 347.65	A, R
5	349.09	Fe	349.06	A, F, M, R
6	349.83	Fe	349.78	A, F, M, R
7	352.69	Fe	352.60, 352.62	A, F, M, R
8	356.65	Fe	356.54	A, F, M, R
9	357.15	Fe	357.01, 357.03	M, R
10	358.14	Fe	358.12	A, F, M, R
11	360.99	Fe	360.89, 361.02	M, R
12	361.98	Fe	361.88	A, F, M, R
13	363.21	Fe	363.15	A, F, M, R
14	364.82	Fe	364.78, 364.95	M, R
15	368.04	Fe	367.99, 368.22	M, R
16	368.78	Fe	368.75, 368.60	M, R
17	370.63	Fe	370.56, 370.79, 370.78	M, R
18	371.00	Fe	370.92	A, M, R
19	371.99	Fe	371.99, 372.26	A, F, M, R
20	373.72	Fe	373.71, 373.49, 373.33	A, F, M, R
21	374.59	Fe	374.56, 374.59	A, F, M, R
22	374.96	Fe	374.95, 374.83	A, F, M, R
23	375.95	Fe	375.82, 376.00	M, R
24	376.44	Fe	376.38, 376.55	F, M, R
25	376.81	Fe	376.72	A, F, M, R
26	378.91	Fe	379.01, 378.79	M, R
27	379.65	Fe	379.50, 379.75	M, R
28	380.02	Fe	379.95, 379.85	A, M, R
29	381.37	Fe	381.30, 381.31	M, R
30	381.62	Fe	381.58	A, F, M, R
31	382.11	Fe	382.04, 382.12	M, R
32	382.61	Fe	382.44, 382.59, 382.78	A, F, M, R
33	383.47	Fe	383.42	A, F, M, R

Table B-2. Spectral Lines of DTFT Exhaust Plume Doped with 50 ppm Fe (continued).

Peak No.	Wavelength (in nm)	Emitter	Contributing Lines (Wavelength in nm)	References
34	384.09	Fe	384.10, 384.04, 383.93	M, R
35	385.07	Fe	385.00, 385.08	A, F, M
36	385.69	Fe	385.64	A, F, M, R
37	386.06	Fe	385.99	A, F, M, R
38	387.29	Fe	387.25, 387.38	M, R
39	387.91	Fe	387.86, 387.80	A, F, M, R
40	388.65	Fe	388.63, 388.70	M, R
41	389.63	Fe	389.57	A, F, M, R
42	390.00	Fe	389.97, 390.29	A, F, M, R
43	390.62	Fe	390.65	A, F, M, R
44	392.35	Fe	392.29, 392.03	A, F, M, R
45	392.84	Fe	392.79	A, F, M, R
46	393.08	Fe	393.03	A, F, M, R
47	404.53	Fe K	404.58 404.41, 404.72	A, F, M, R A, F, M, R
48	406.38	Fe	406.36	A, F, M, R
49	407.24	Fe	407.17	A, F, M, R
50	413.39	Fe	413.21, 413.47	M, R
51	420.27	Fe	420.20, 420.40	M, R
52	421.75	Fe	421.62, 421.94	M, R

Table B-3. Spectral Lines of DTFT Exhaust Plume Doped with 10 ppm Cr.

Peak No.	Wavelength (in nm)	Emitter	Contributing Lines (Wavelength in nm)	References
1	357.89	Cr	357.87	A, F, M, R
2	359.38	Cr	359.35	A, F, M, R
3	360.62	Cr	360.53	A, F, M, R
4	404.41	K	404.41	A, F, M, R
5	404.78	K	404.72	A, F, M, R
6	425.56	Cr	425.43	A, F, M, R

Table B-4. Spectral Lines of DTFT Exhaust Plume Doped with 50 ppm Co.

Peak No.	Wavelength (in nm)	Emitter	Contributing Lines (Wavelength in nm)	References
1	333.42	Co	333.41, 333.34	A, M
2	335.54	Co	335.44	A, F, M
3	336.78	Co	336.71	A, F, M
4	338.65	Co	338.52	A, F, M
5	338.90	Co	338.82	A, F, M, R
6	339.52	Co	339.54	A, F, M, R
7	340.64	Co	340.51	A, F, M, R
8	341.01	Co	340.92	A, F, M, R
9	341.26	Co	341.23, 341.26	A, F, M, R
10	341.76	Co	341.72	A, F, M, R
11	343.38	Co	343.30, 343.16	A, F, M, R
12	344.37	Co	344.36, 344.29	A, F, M, R
13	344.99	Co	344.92, 344.94	A, F, M, R
14	345.49	Co	345.35, 345.52	A, F, M, R
15	346.36	Co	346.28	A, F, M, R
16	346.61	Co	346.58	A, F, M, R
17	347.47	Co	347.40	A, F, M, R
18	348.47	Co	348.34	A, F, M, R
19	348.96	Co	348.94	A, F, M, R
20	349.71	Co	349.57	A, F, M, R
21	350.33	Co	350.23	A, F, M, R
22	350.70	Co	350.63	A, F, M, R
23	351.07	Co	350.98, 351.04	A, F, M, R
24	351.45	Co	351.26, 351.35	A, F, M, R
25	352.19	Co	352.16, 352.01	A, F, M, R
26	352.44	Co	352.34	A, M, R
27	353.06	Co	352.98, 352.68, 352.90	A, F, M, R
28	353.43	Co	353.34	A, F, M, R
29	355.17	Co	355.06	A, F, M
30	356.16	Co	356.09	A, F, M, R
31	356.53	Co	356.50	A, F, M
32	357.02	Co	356.94	A, F, M, R
33	357.64	Co	357.54, 357.50	A, F, M, R

Table B-4. Spectral Lines of DTFT Exhaust Plume Doped with 50 ppm Co (continued).

Peak No.	Wavelength (in nm)	Emitter	Contributing Lines (Wavelength in nm)	References
34	358.76	Co	358.72, 358.52	A, F, M, R
35	359.62	Co	359.49	A, F, M, R
36	360.24	Co	360.21	A, F, M, R
37	362.84	Co	362.78	A, F, M, R
38	363.21	Co	363.14	A, F, M
39	364.82	Co	364.77	A, F, M
40	365.32	Co	365.25	A, F, M
41	370.51	Co	370.41	A, F, M
42	374.59	Co	374.55	A, F, M, R
43	384.58	Co	384.55, 384.20	A, F, M, R
44	386.18	Co	386.12	A, F, M
45	387.42	Co	387.31, 387.40	A, F, M, R
46	388.28	Co	388.19	A, F, M, R
47	389.51	Co	389.41, 389.50	A, F, M, R
48	390.99	Co	390.99	A, F, M
49	393.70	Co	393.60	A, F, M, R
50	394.19	Co	394.17, 394.09	A, F, M
51	395.30	Co	395.29, 395.23	A, F, M
52	395.79	Co	395.79	A, F, M
53	397.52	Co	397.47	A, F, M
54	398.01	Co	397.95, 397.87	A, F, M
55	399.61	Co	399.53, 399.79	A, F, M, R
56	402.19	Co	402.09	A, F, M, R
57	402.81	Co	402.70	A, M
58	404.53	Co	404.54	A, F, M, R
		K	404.41, 404.72	A, F, M, R
59	405.89	Co	405.72, 405.82	A, M
60	406.75	Co	406.64	A, F, R
61	409.33	Co	409.24	A, F, M, R
62	411.05	Co	411.05	A, F, M, R
63	412.16	Co	412.13, 411.88	A, F, M, R
64	419.17	Co	419.07	A, F, M, R
65	425.32	Co	425.23	A, M

Table B-5. Spectral Lines of DTFT Exhaust Plume Doped with 10 ppm Cu.

Peak No.	Wavelength (in nm)	Emitter	Contributing Lines (Wavelength in nm)	References
1	324.81	Cu	324.75	A, F, M, R
2	327.43	Cu	327.40	A, F, M, R

Table B-6. Spectral Lines of DTFT Exhaust Plume Doped with 2 ppm Mn.

Peak No.	Wavelength (in nm)	Emitter	Contributing Lines (Wavelength in nm)	References
1	403.42	Mn	403.08, 403.31, 403.45	A, F, M, R
2	404.53	K	404.41	A, F, M, R
3	404.78	K	404.72	A, F, M, R

Table B-7. Spectral Lines of DTFT Exhaust Plume Doped with 5 ppm Ca.

Peak No.	Wavelength (in nm)	Emitter	Contributing Lines (Wavelength in nm)	References
1	404.31	K	404.41, 404.72	A, F, M, R
2	422.61	Ca	422.67	A, F, M, R

Table B-8. Spectral Lines of DTFT Exhaust Plume Doped with 50 ppm Al.

Peak No.	Wavelength (in nm)	Emitter	Contributing Lines (Wavelength in nm)	References
1	394.48	Al	394.40	A, F, M, R
2	396.08	Al	396.15	A, F, M, R
3	404.43	K	404.41	A, F, M, R
4	404.68	K	404.72	A, F, M, R

Table B-9. Spectral Lines of DTFT Exhaust Plume Doped with 50 ppm Ag.

Peak No.	Wavelength (in nm)	Emitter	Contributing Lines (Wavelength in nm)	References
1	328.03	Ag	328.07	A, F, M, R
2	338.25	Ag	338.29	A, F, M, R

Table B-10. Spectral Lines of DTFT Exhaust Plume Doped with 50 ppm Mg.

Peak No.	Wavelength (in nm)	Emitter	Contributing Lines (Wavelength in nm)	References
1	362.06	MgOH	362.4	A
2	362.80	MgO(H)	362.7	A, F
3	369.48	MgO(H)	369.6	A, F
4	370.22	MgOH MgO(H)	370.2 370.3	A A, F
5	370.71	MgO(H)	370.7	A, F
6	371.94	MgOH	371.9	A, F
7	373.05	MgOH MgO(H)	372.9 373.1	A A, F
8	374.9	MgO(H)	375.1	A, F
9	376.88	MgOH	376.7	A
10	378.6	MgOH	378.4	A
11	379.22	MgOH	379.1	A
12	380.08	MgO(H)	380.1	A, F
13	380.82	MgO MgO(H)	380.7 381.0	A, F A, F
14	381.31	MgO(H)	381.4	A
15	381.56	MgO(H)	381.5	A, F
16	382.05	MgO(H)	382.2	A, F
17	382.3	MgO(H) MgO(H)	382.2 382.3	A, F A
18	382.91	Mg	382.94	A, F, M, R
19	383.28	Mg	383.23	A, F, M, R
20	383.53	MgO(H)	383.4	F
21	384.51	MgOH	384.6	A
22	384.76	MgO(H)	384.8	A, F
23	385.5	MgO(H)	385.5	A, F
24	385.99	MgO(H)	385.9	A, F
25	387.96	MgO(H) MgO(H)	387.7 388.2	A A, F
26	391.4	MgO(H) MgO(H)	391.2 391.4	A A, F

Reference Note

The letter codes used in the preceding tables refer to the following references. The references are repeated here for the reader's convenience. The number shown for each reference given below refers to that reference as it is mentioned in the main text of this report and as it is numbered in the complete reference list.

Code	Reference Number	Reference
A	11	C. Th. J. Alkemade and R. Herrmann, *Fundamentals of Analytical Flame Spectroscopy*, Wiley, New York, NY, 1979.
F	18	R. Mavrodineanu and H. Boiteux, *Flame Spectroscopy*, Wiley, New York, NY, 1965.
M	15	F.M. Phelps, *M.I.T. Wavelength Tables, Volume 2: Wavelengths by Element*, M.I.T. Press, Cambridge, MA 1982.
R	17	J. Reader, C.H. Corliss, W.L. Wiese, and G.A. Martin, *Wavelengths and Transition Probabilities for Atoms and Atomic Ions, Part I. Wavelengths, Part II. Transition Probabilities*, NSRDS–NBS 68, U.S. Govt. Printing Office, Washington, DC, 1980.

APPENDIX C

SSME ALLOYS: DTFT EXHAUST PLUME SPECTRA AND LINE IDENTIFICATION TABLES

SSME ALLOYS: DTFT EXHAUST PLUME SPECTRA AND LINE IDENTIFICATION TABLES

List of Figures and Tables

Figures

Tables

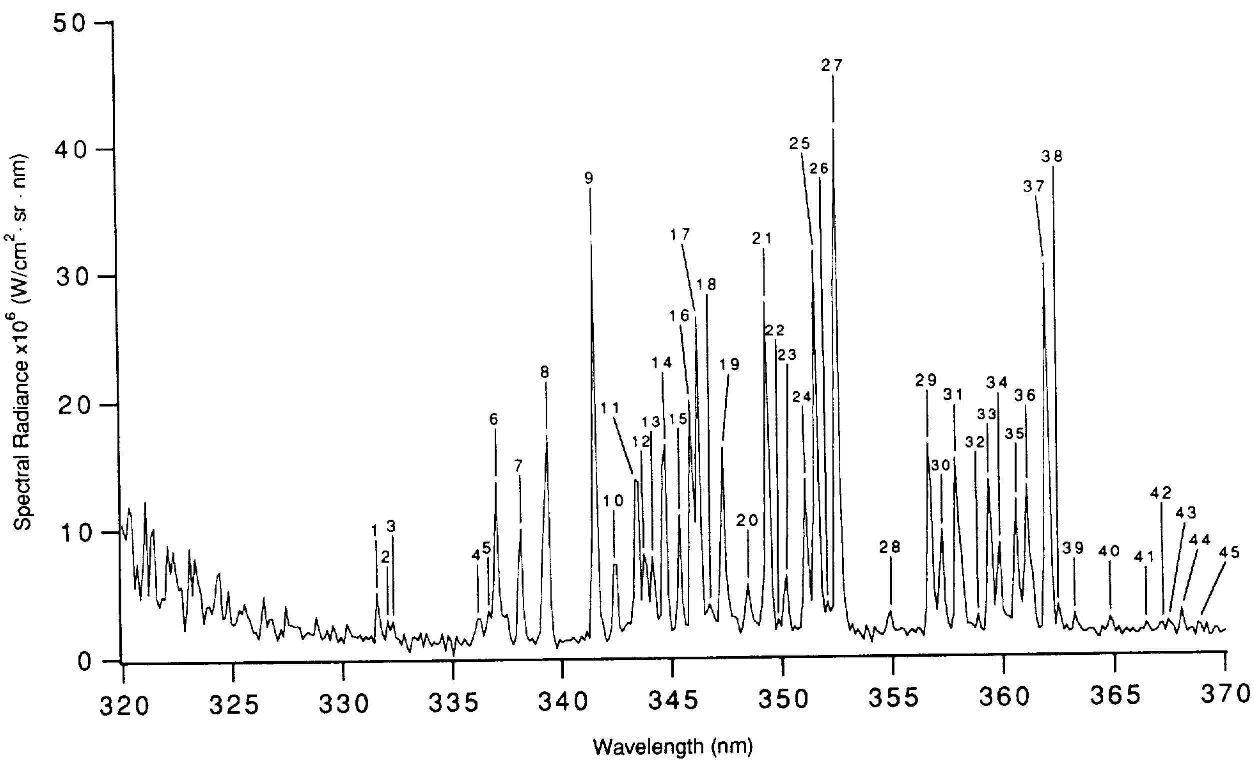

Fig. C-1a. Inconel 718, 50 ppm; DTFT Plume Spectrum, 320 to 370 nm.

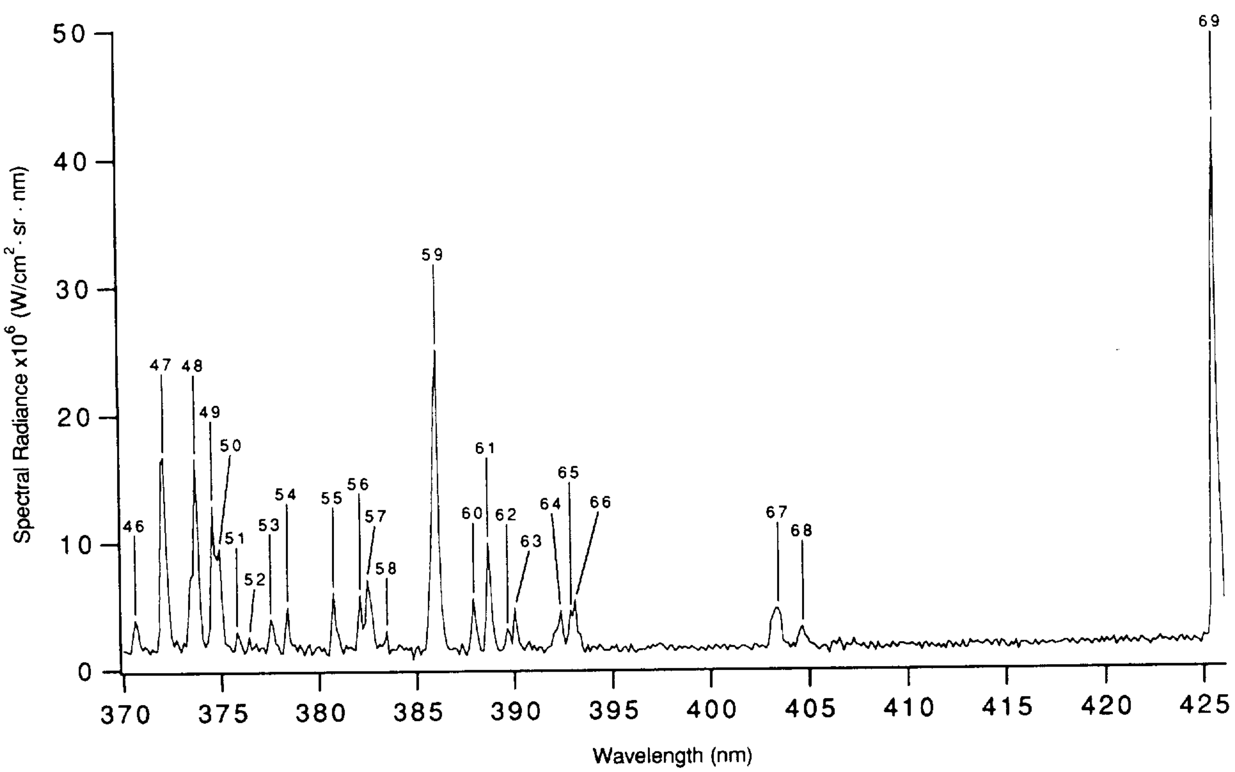

Fig. C-1b. Inconel 718, 50 ppm; DTFT Plume Spectrum, 370 to 426 nm.

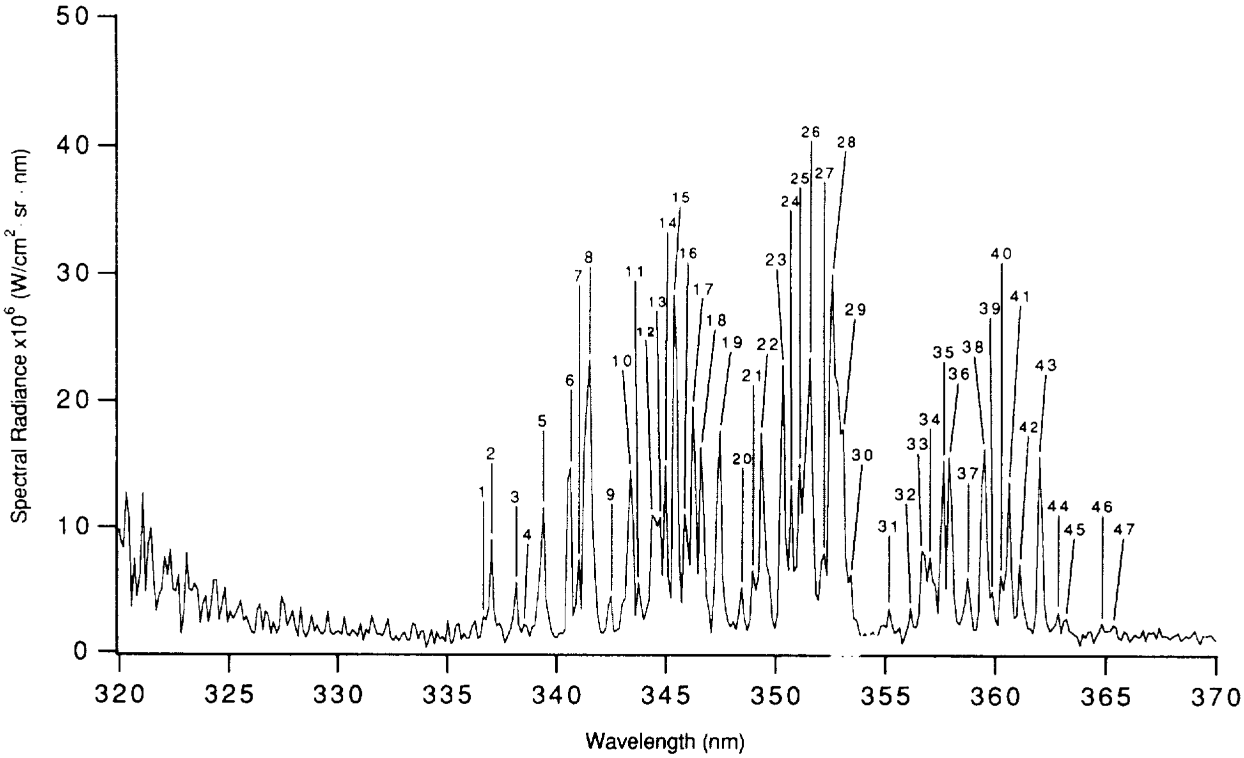

Fig. C-2a. Haynes 188, 50 ppm; DTFT Plume Spectrum, 320 to 370 nm.

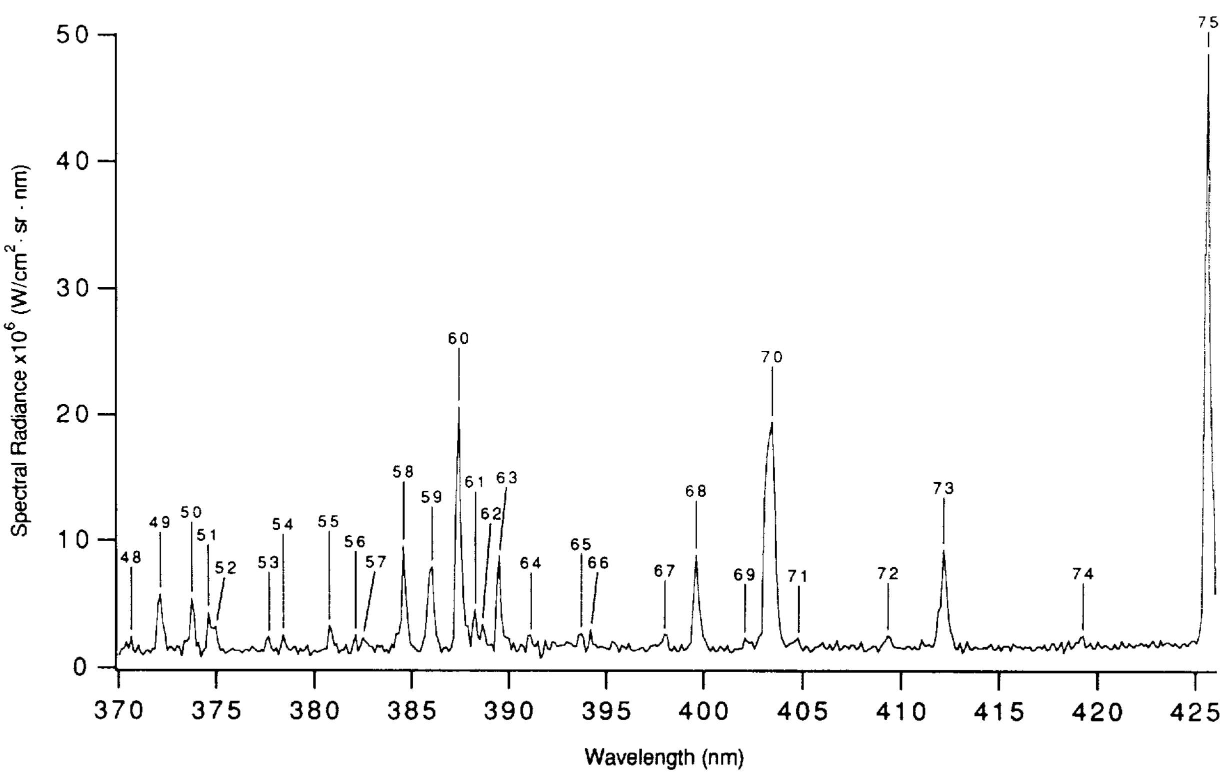

Fig. C-2b. Haynes 188, 50 ppm; DTFT Plume Spectrum, 370 to 426 nm.

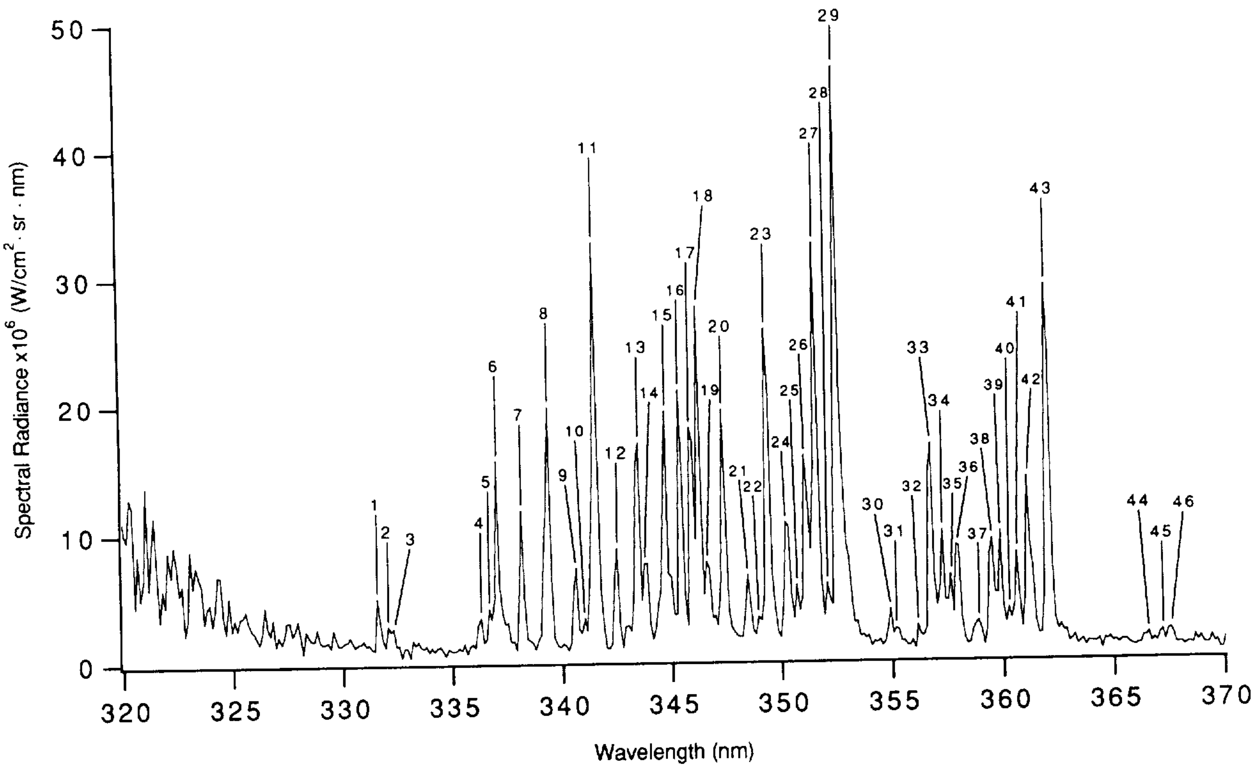

Fig. C-3a. MAR-M 246+Hf, 50 ppm; DTFT Plume Spectrum, 320 to 370 nm.

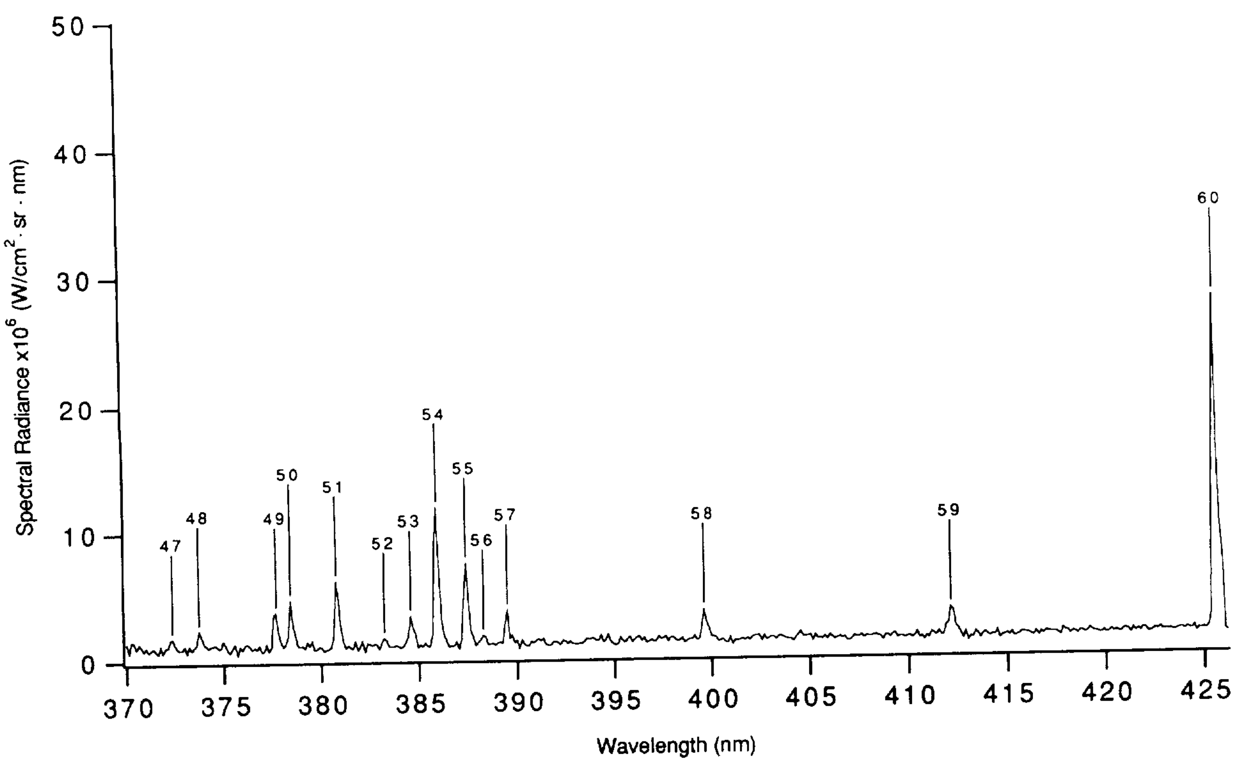

Fig. C-3b. MAR-M 246+Hf, 50 ppm; DTFT Plume Spectrum, 370 to 426 nm.

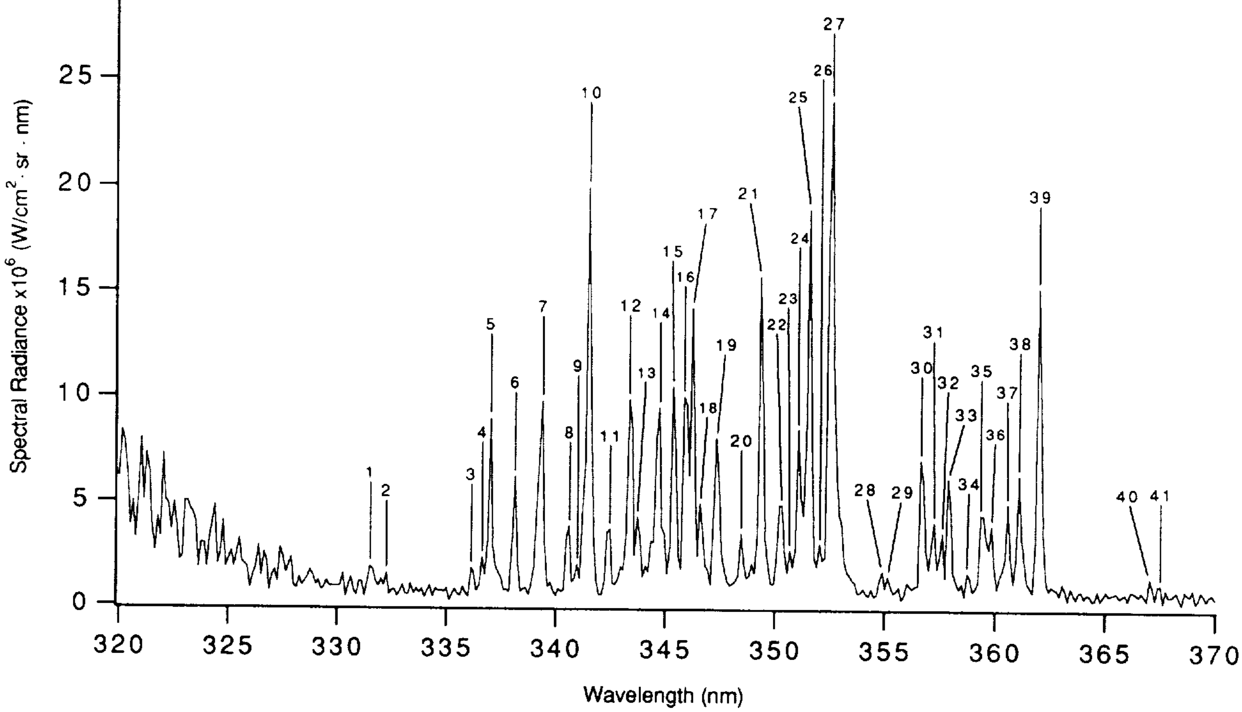

Fig. C-4a. Waspaloy X, 50 ppm; DTFT Plume Spectrum, 320 to 370 nm.

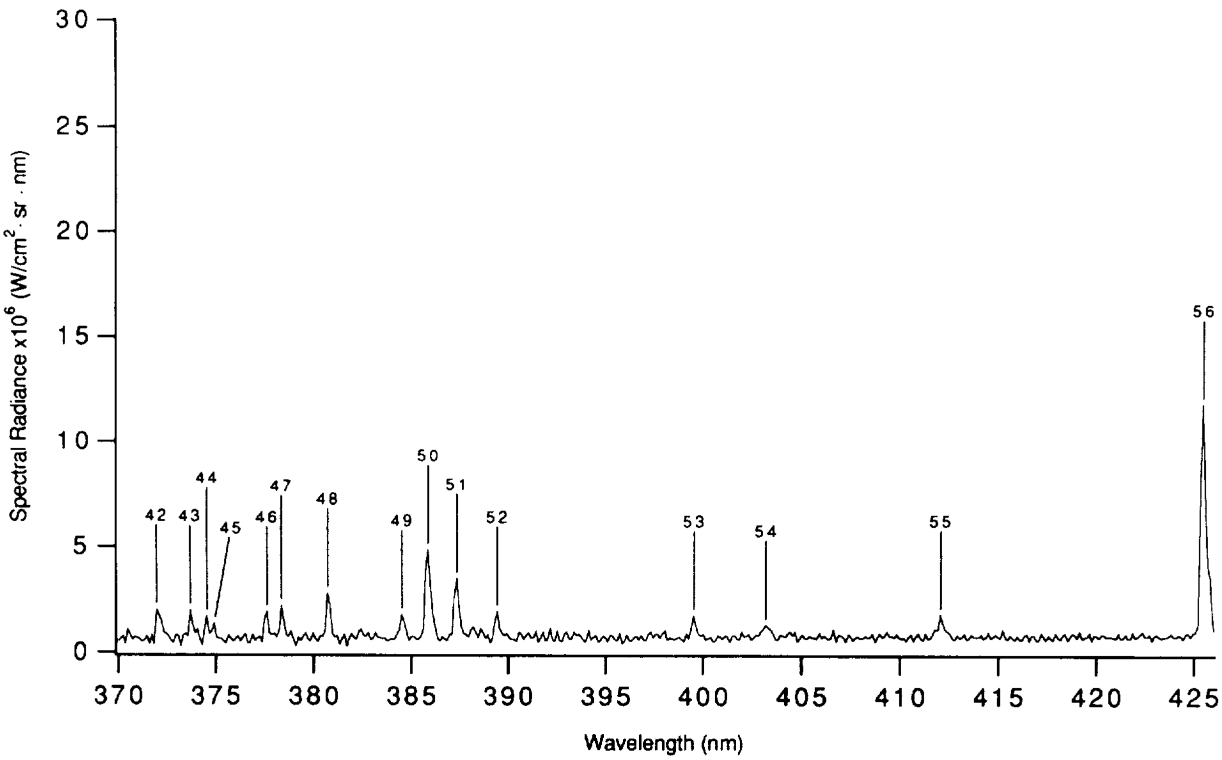

Fig. C-4b. Waspaloy X, 50 ppm; DTFT Plume Spectrum, 370 to 426 nm.

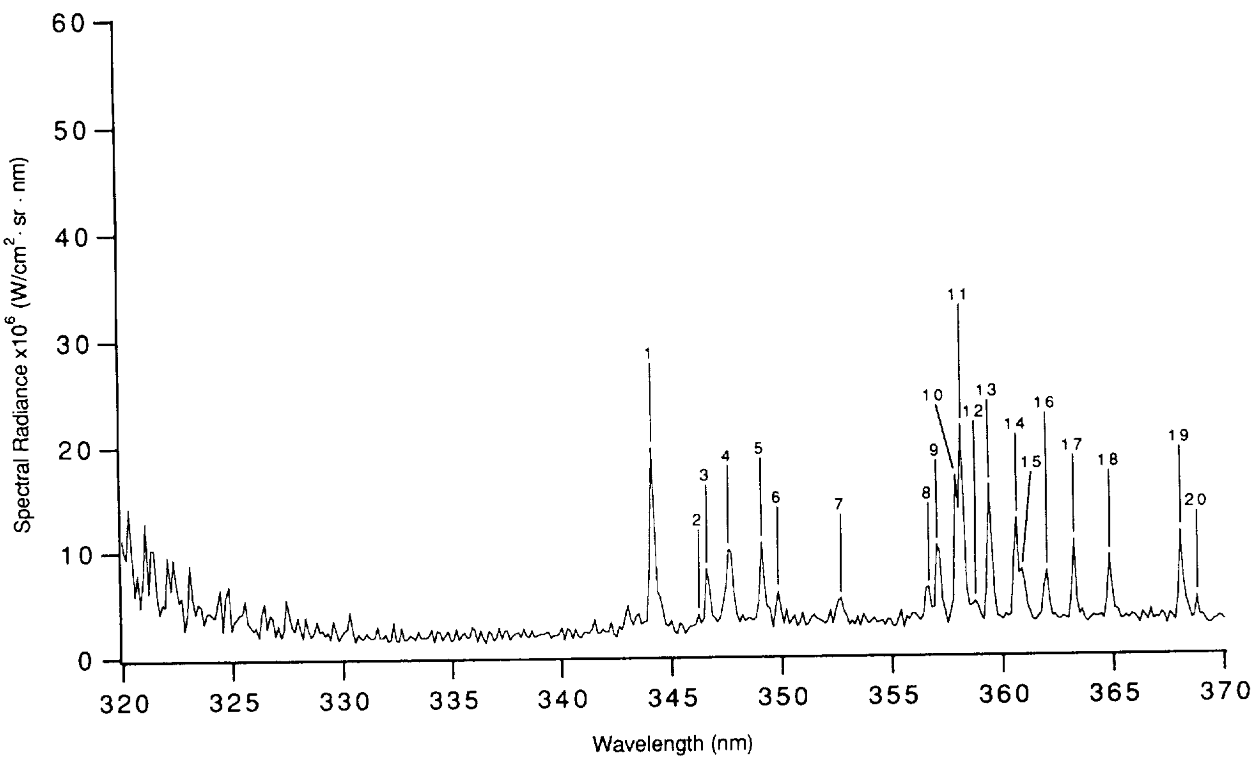

Fig. C-5a. AISI 440C, 50 ppm; DTFT Plume Spectrum, 320 to 370 nm.

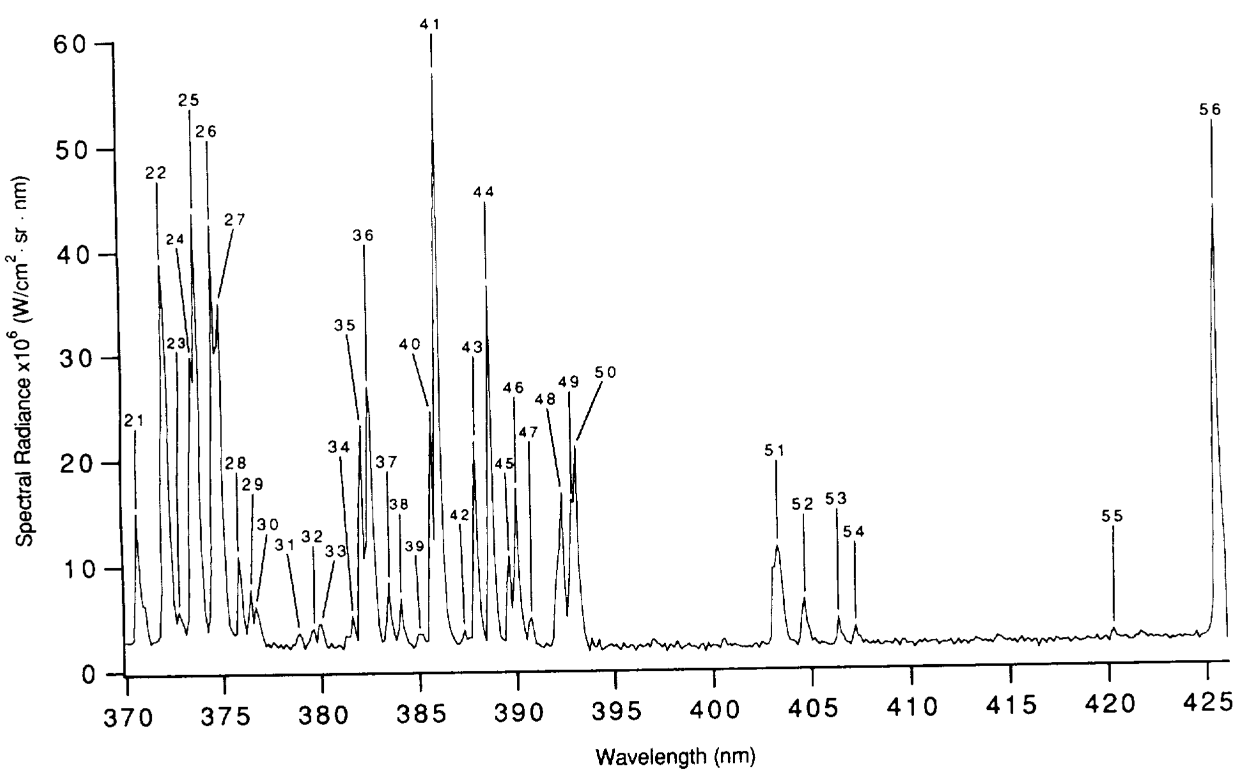

Fig. C-5b. AISI 440C, 50 ppm; DTFT Plume Spectrum, 370 to 426 nm.

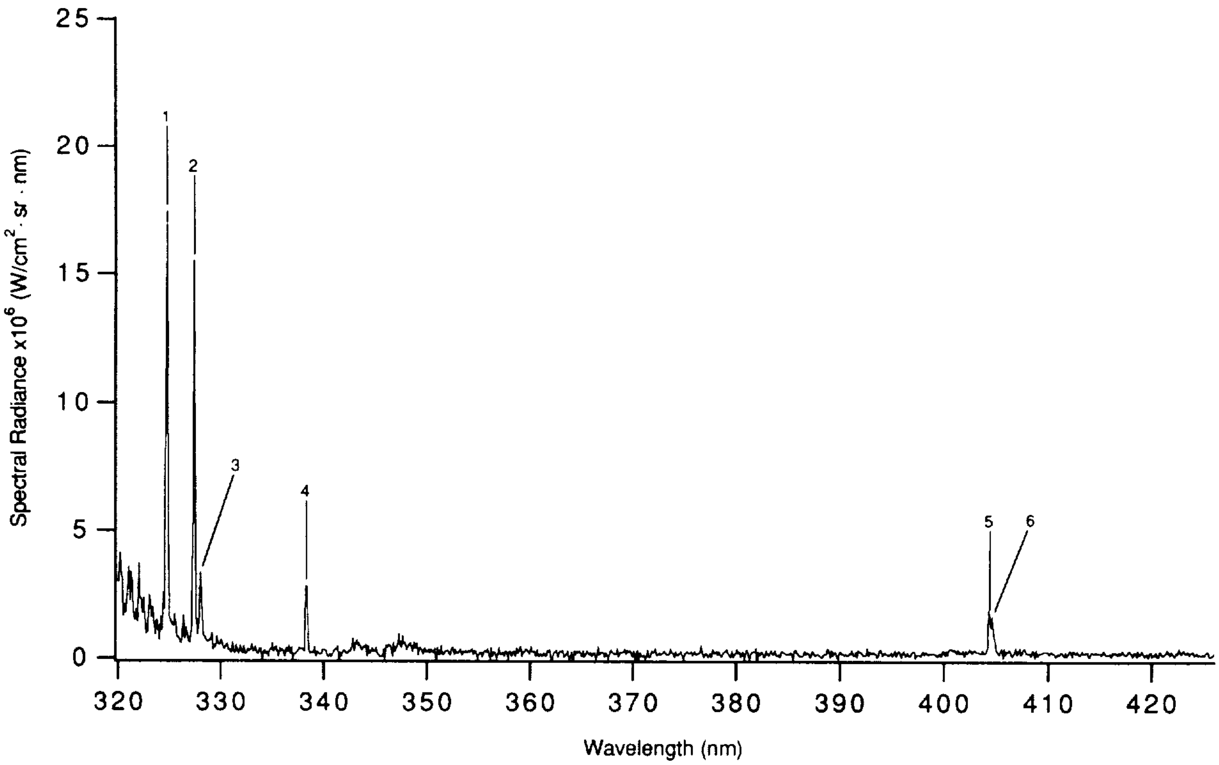

Fig. C-6. NARloy-A, 50 ppm; DTFT Plume Spectrum, 320 to 426 nm.

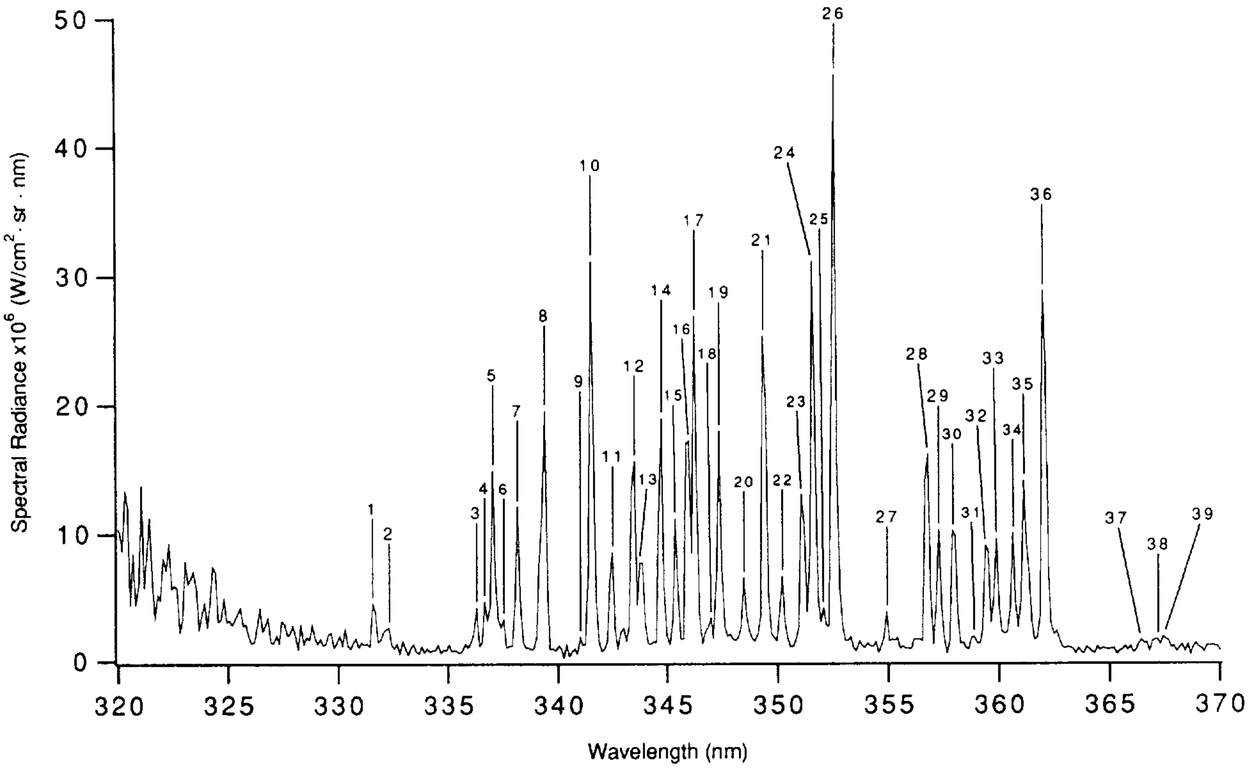

Fig. C-7a. NiCrAlY, 50 ppm; DTFT Plume Spectrum, 320 to 370 nm.

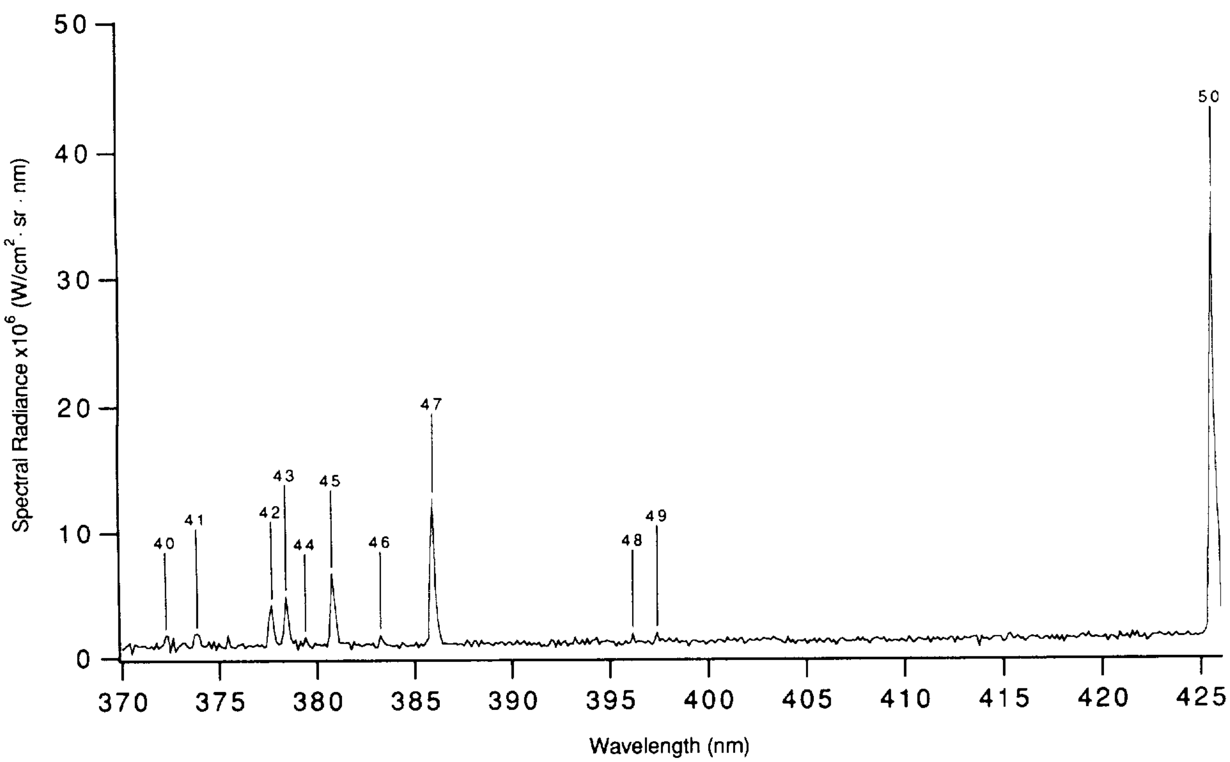

Fig. C-7b. NiCrAlY, 50 ppm; DTFT Plume Spectrum, 370 to 426 nm.

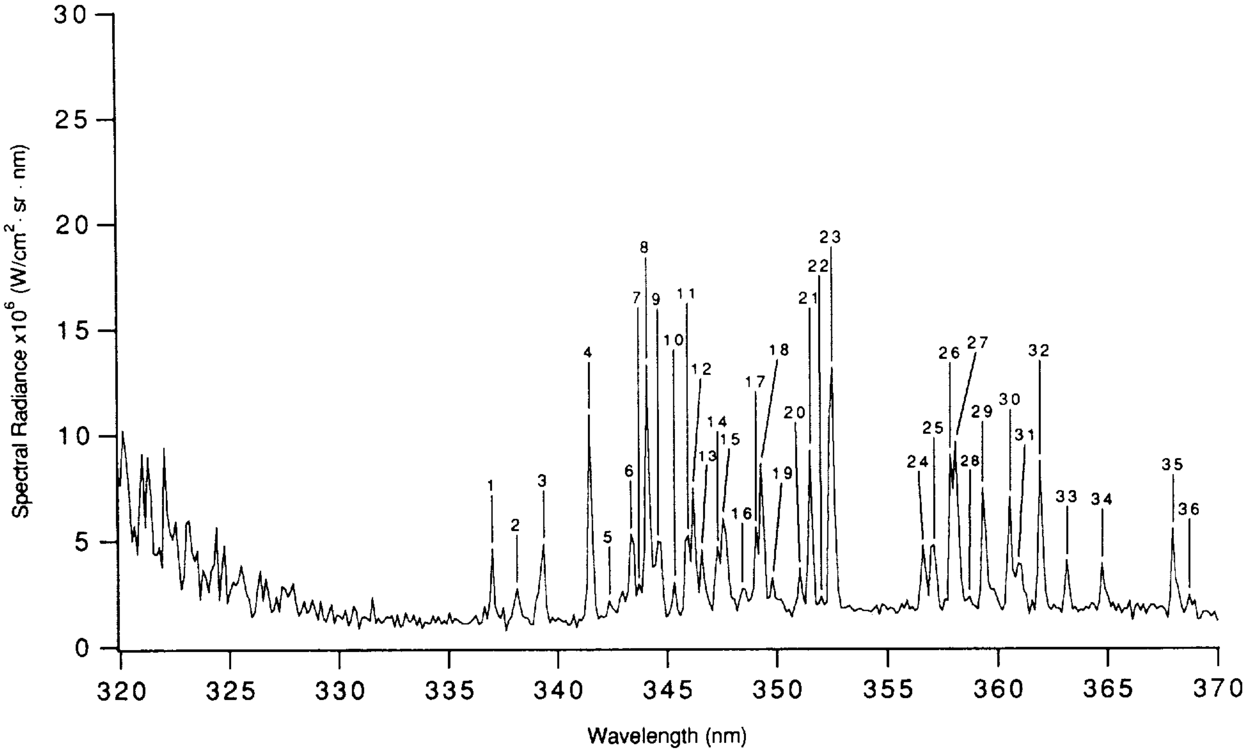

Fig. C-8a. 347 CRES, 50 ppm; DTFT Plume Spectrum, 320 to 370 nm.

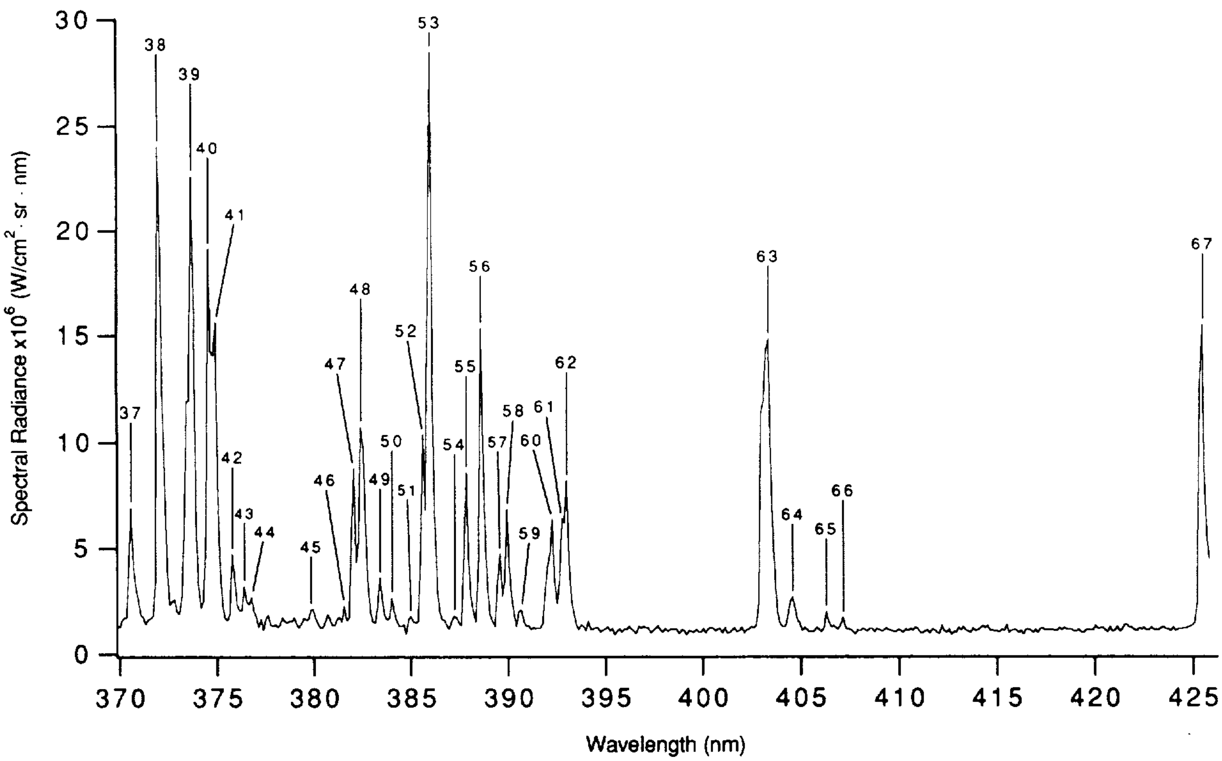

Fig. C-8b. 347 CRES, 50 ppm; DTFT Plume Spectrum, 370 to 426 nm.

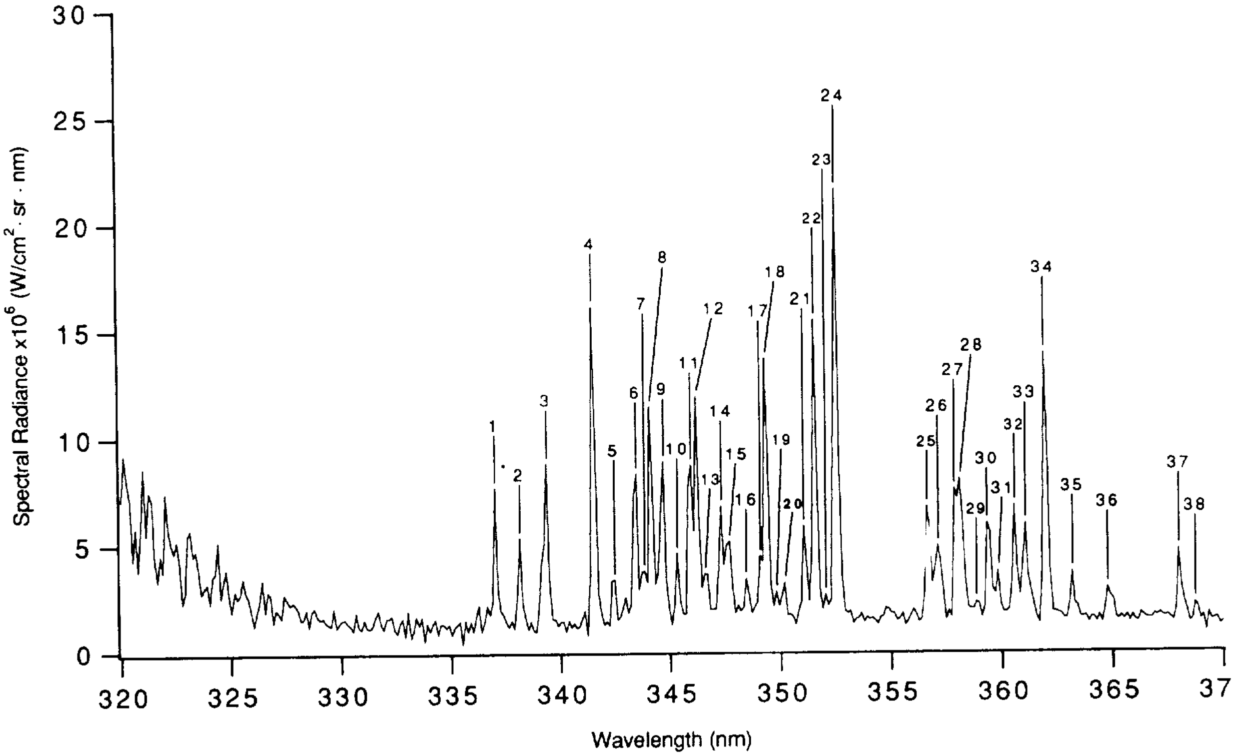

Fig. C-9a. A-286 CRES, 50 ppm; DTFT Plume Spectrum, 320 to 370 nm.

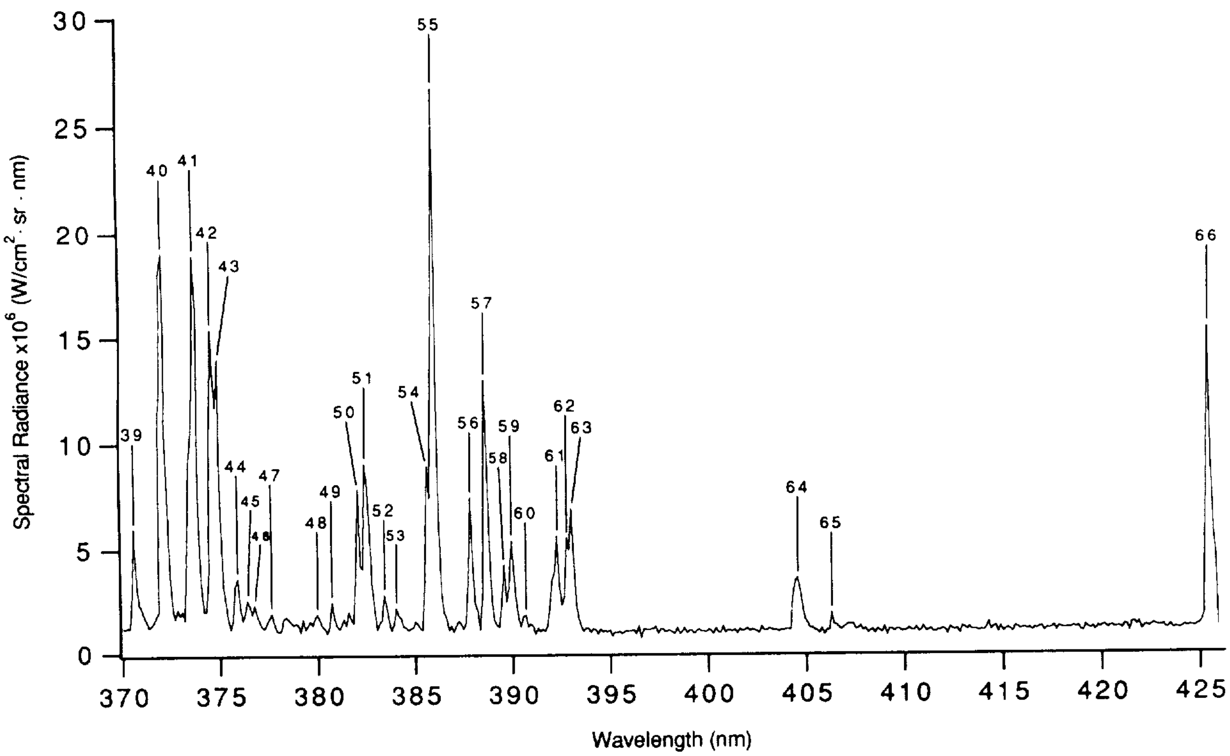

Fig. C-9b. A-286 CRES, 50 ppm; DTFT Plume Spectrum, 370 to 426 nm.

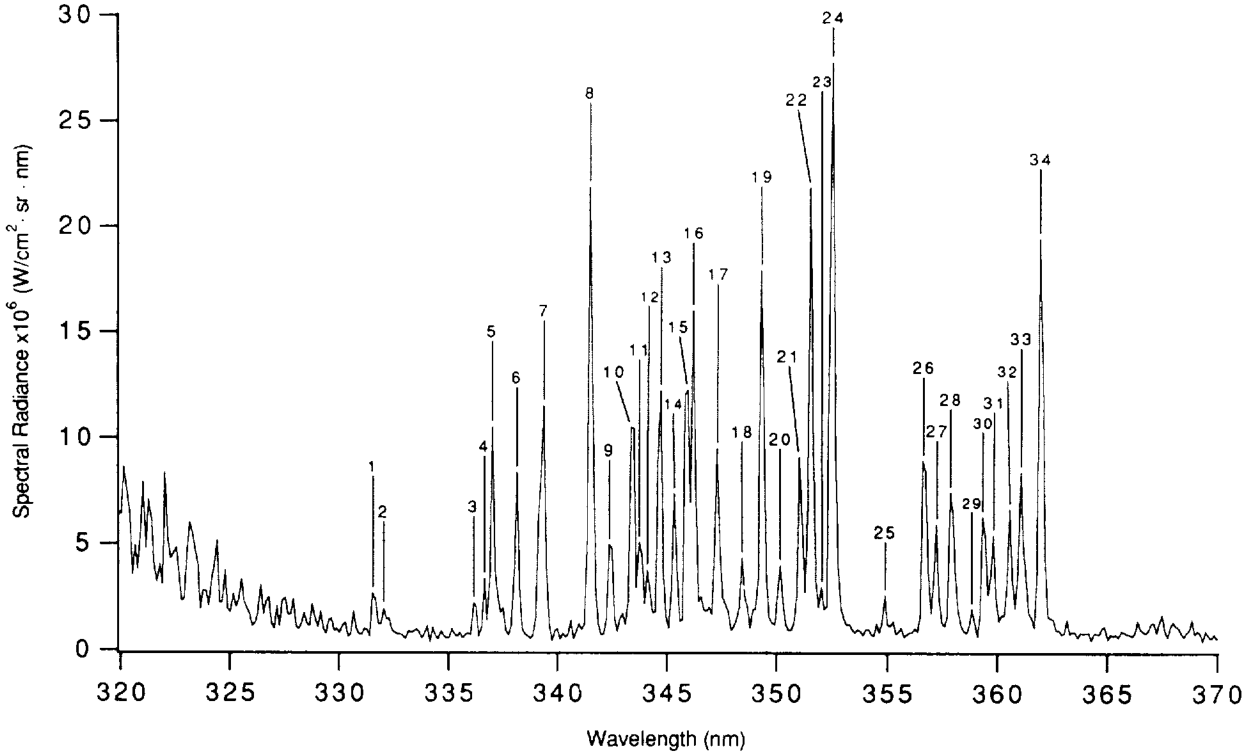

Fig. C-10a. Inconel 625, 50 ppm; DTFT Plume Spectrum, 320 to 370 nm.

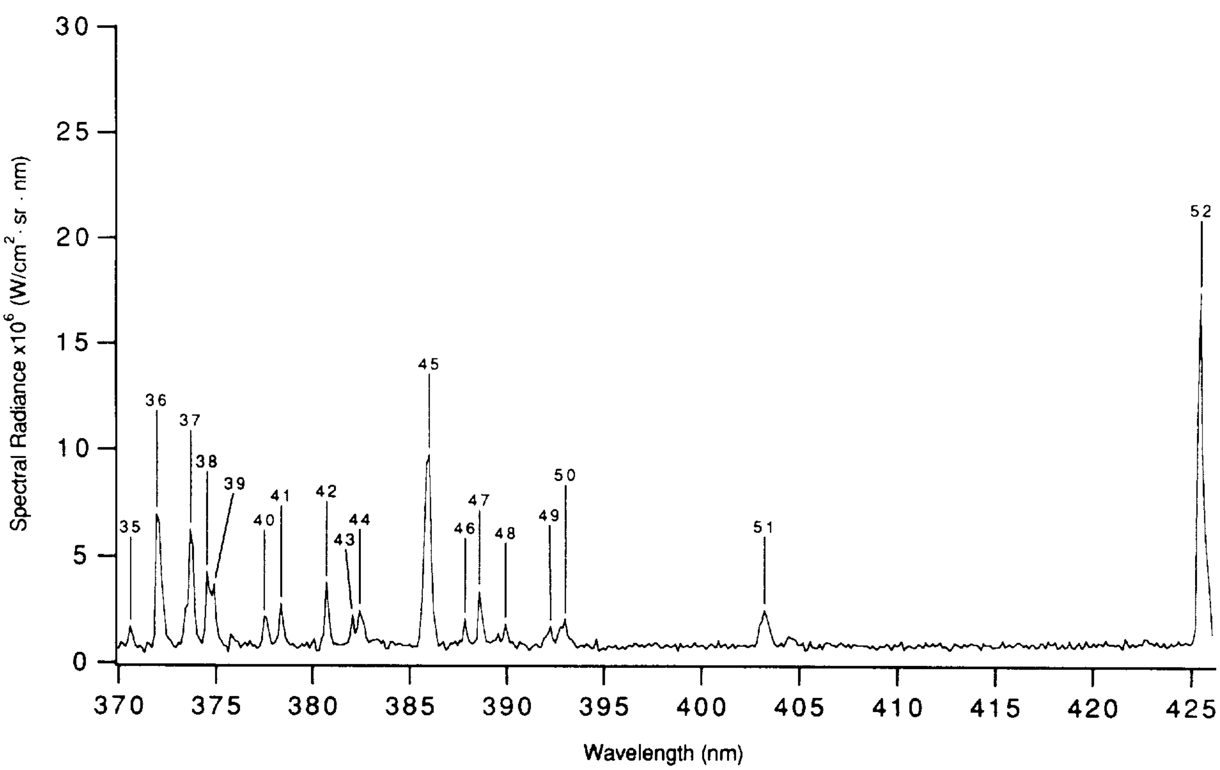

Fig. C-10b. Inconel 625, 50 ppm; DTFT Plume Spectrum, 370 to 426 nm.

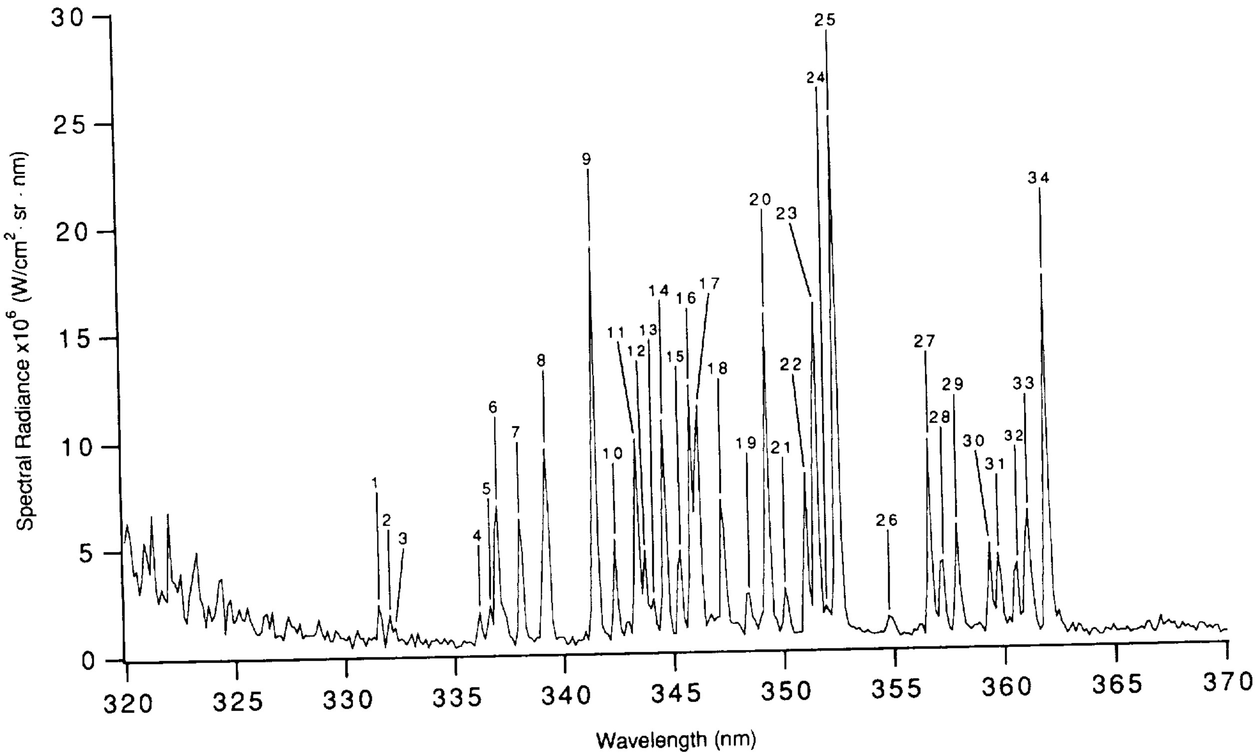

Fig. C-11a. Inconel 600, 50 ppm; DTFT Plume Spectrum, 320 to 370 nm.

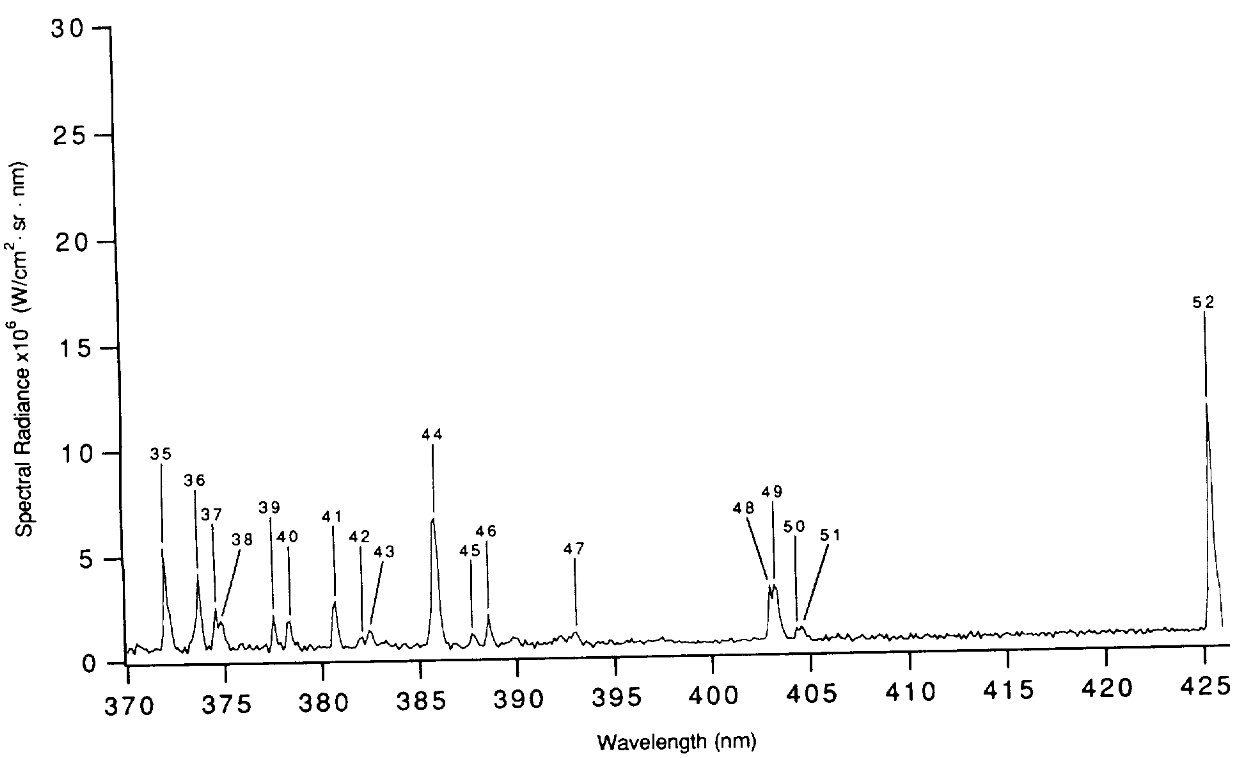

Fig. C-11b. Inconel 600, 50 ppm; DTFT Plume Spectrum, 370 to 426 nm.

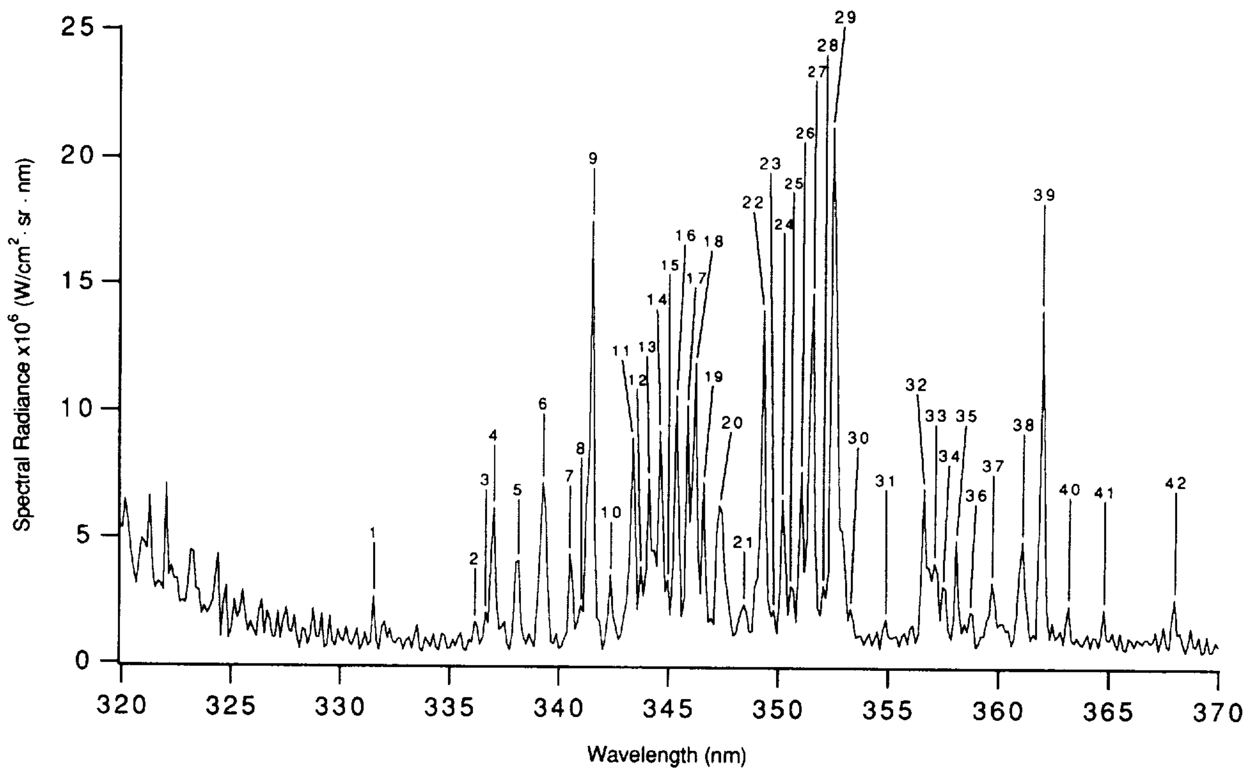

Fig. C-12a. Incoloy 903, 50 ppm; DTFT Plume Spectrum, 320 to 370 nm.

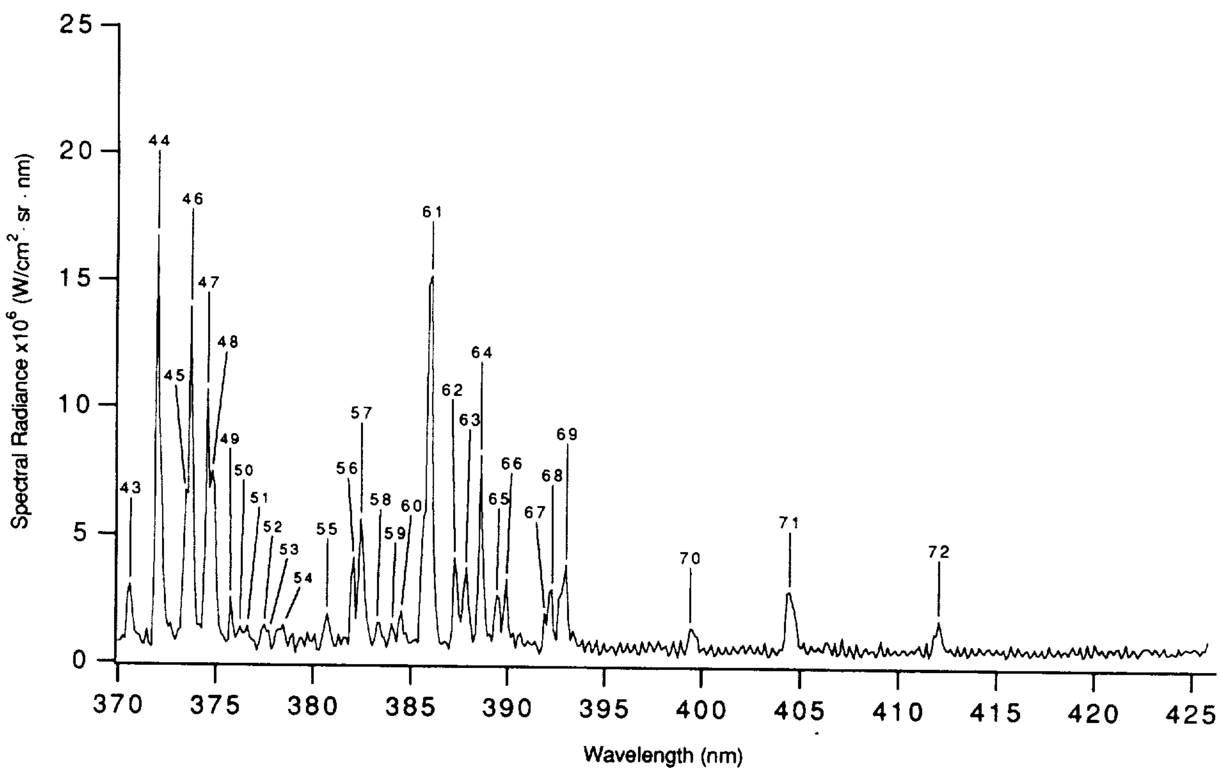

Fig. C-12b. Incoloy 903, 50 ppm; DTFT Plume Spectrum, 370 to 426 nm.

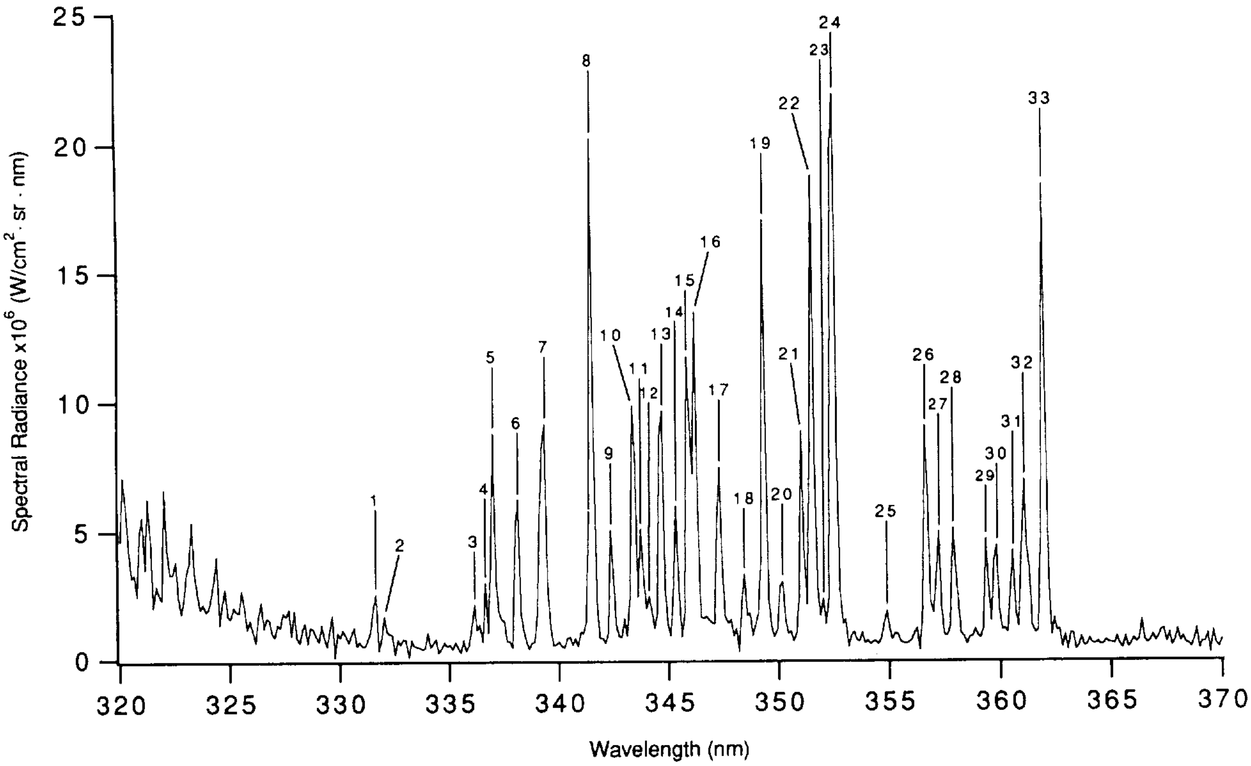

Fig. C-13a. Inconel X-750, 50 ppm; DTFT Plume Spectrum, 320 to 370 nm.

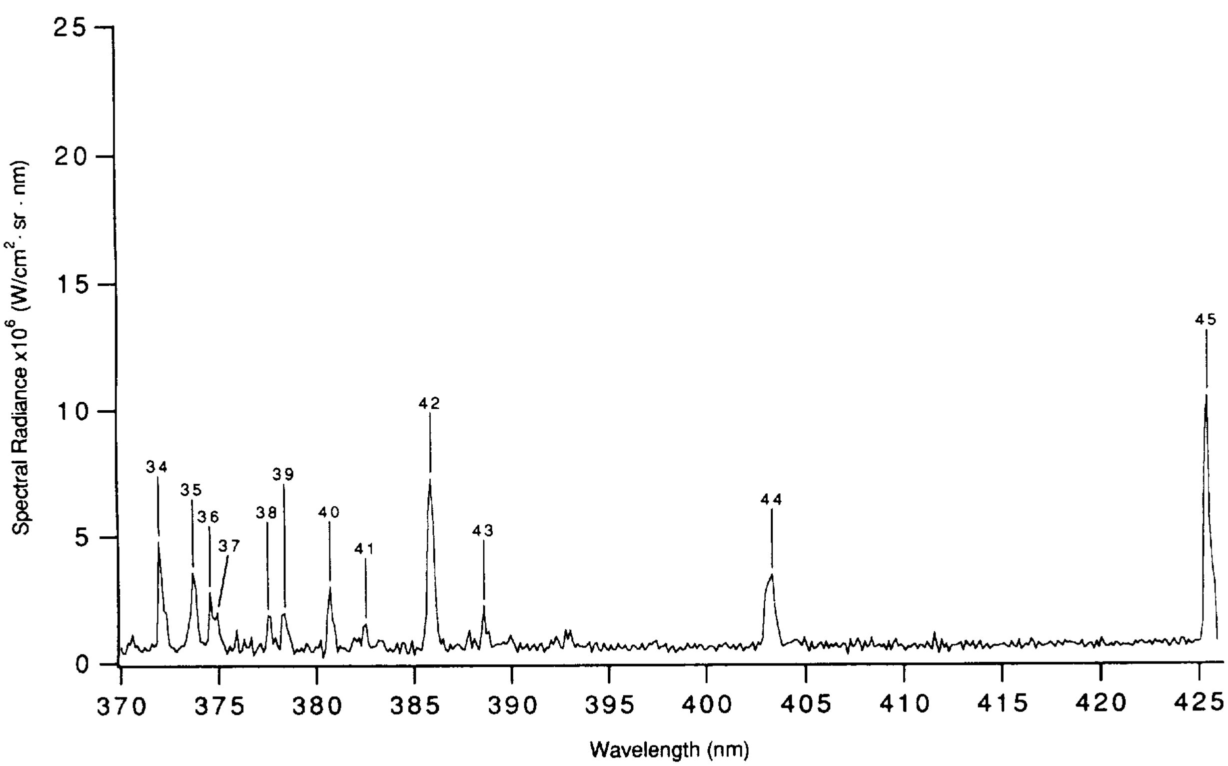

Fig. C-13b. Inconel X-750, 50 ppm; DTFT Plume Spectrum, 370 to 426 nm.

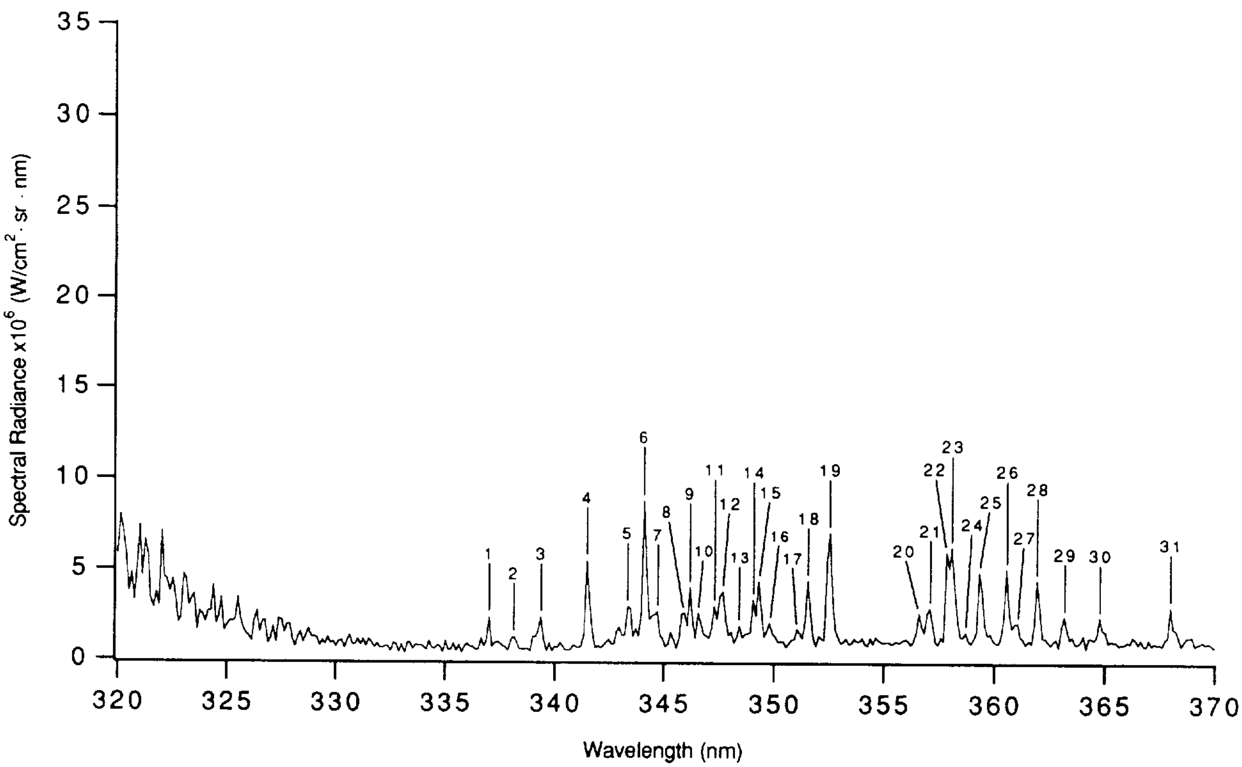

Fig. C-14a. Armco 21-6-9, 50 ppm; DTFT Plume Spectrum, 320 to 370 nm.

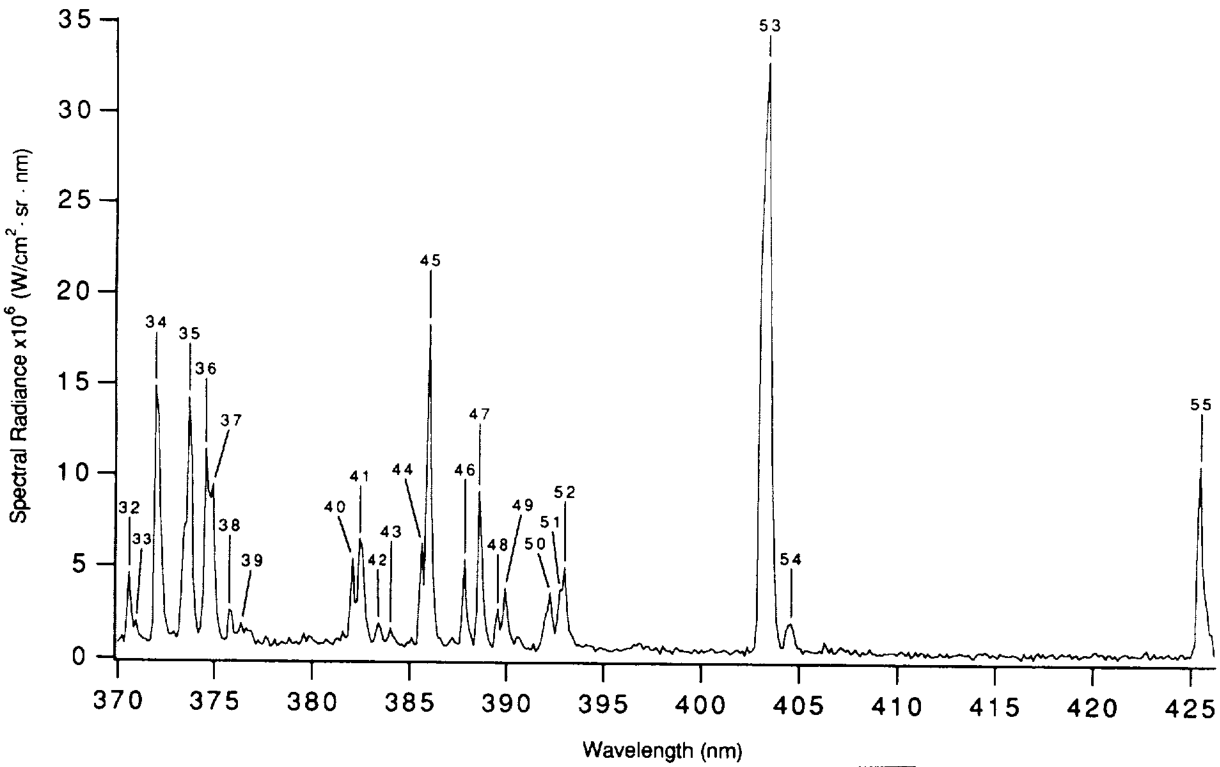

Fig. C-14b. Armco 21-6-9, 50 ppm; DTFT Plume Spectrum, 370 to 426 nm.

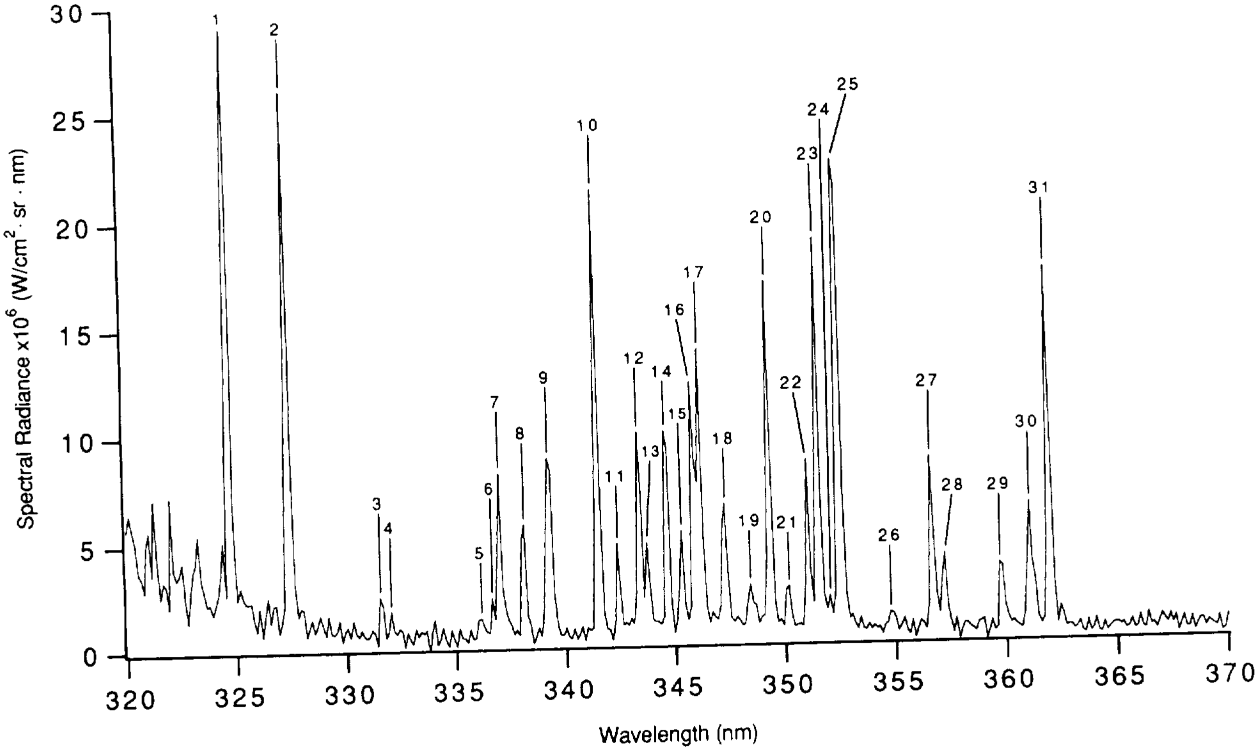

Fig. C-15a. K-Monel, 50 ppm; DTFT Plume Spectrum, 320 to 370 nm.

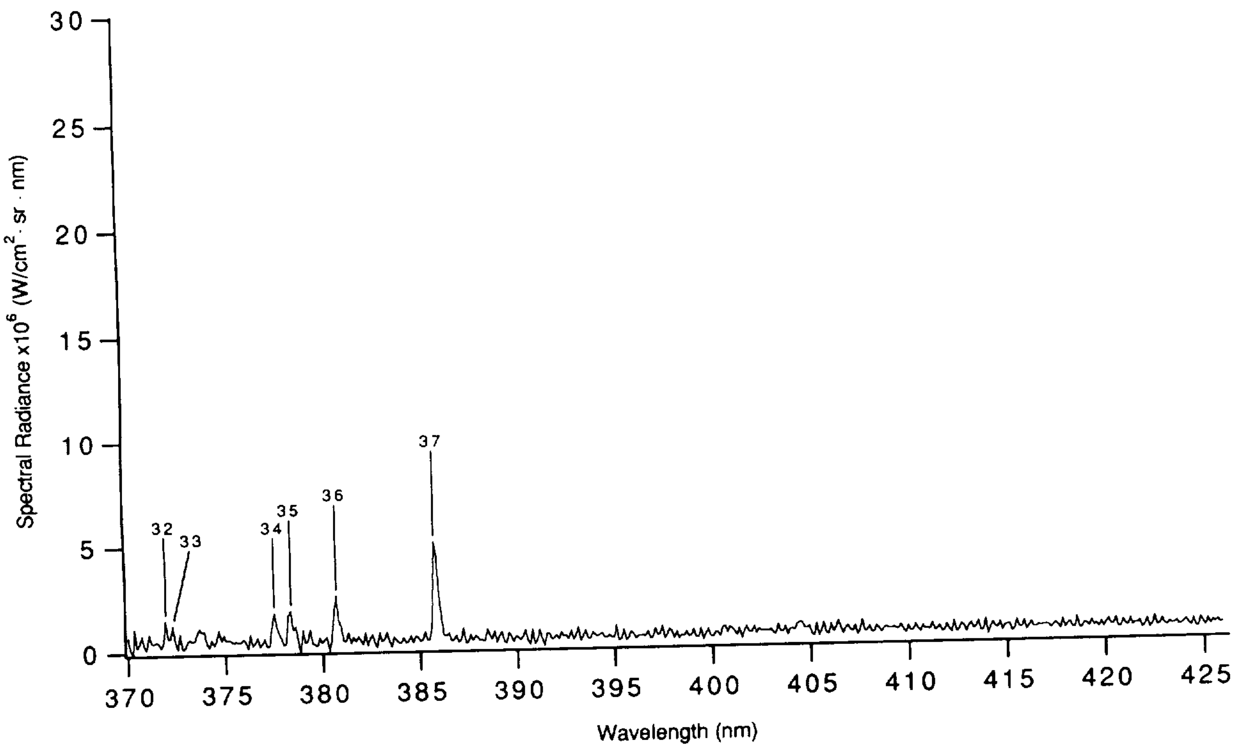

Fig. C-15b. K-Monel, 50 ppm; DTFT Plume Spectrum, 370 to 426 nm.

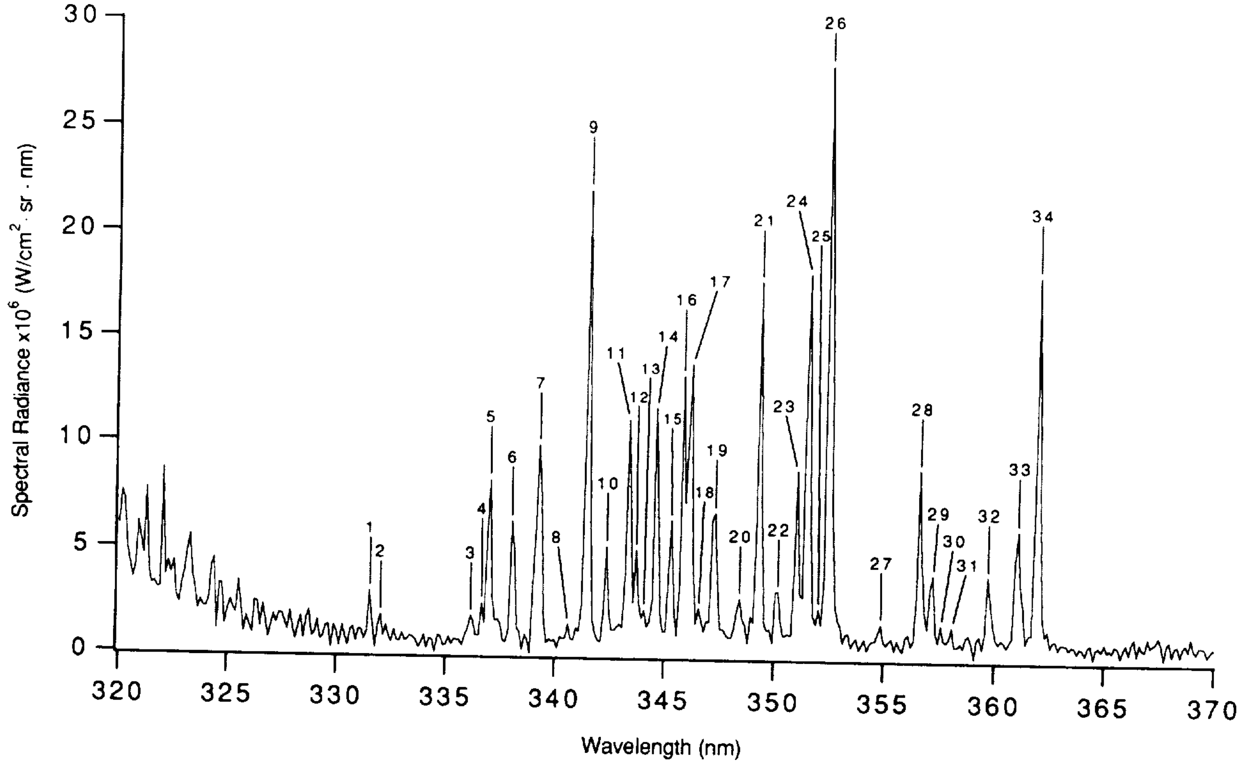

Fig. C-16a. Hastelloy B, 50 ppm; DTFT Plume Spectrum, 320 to 370 nm.

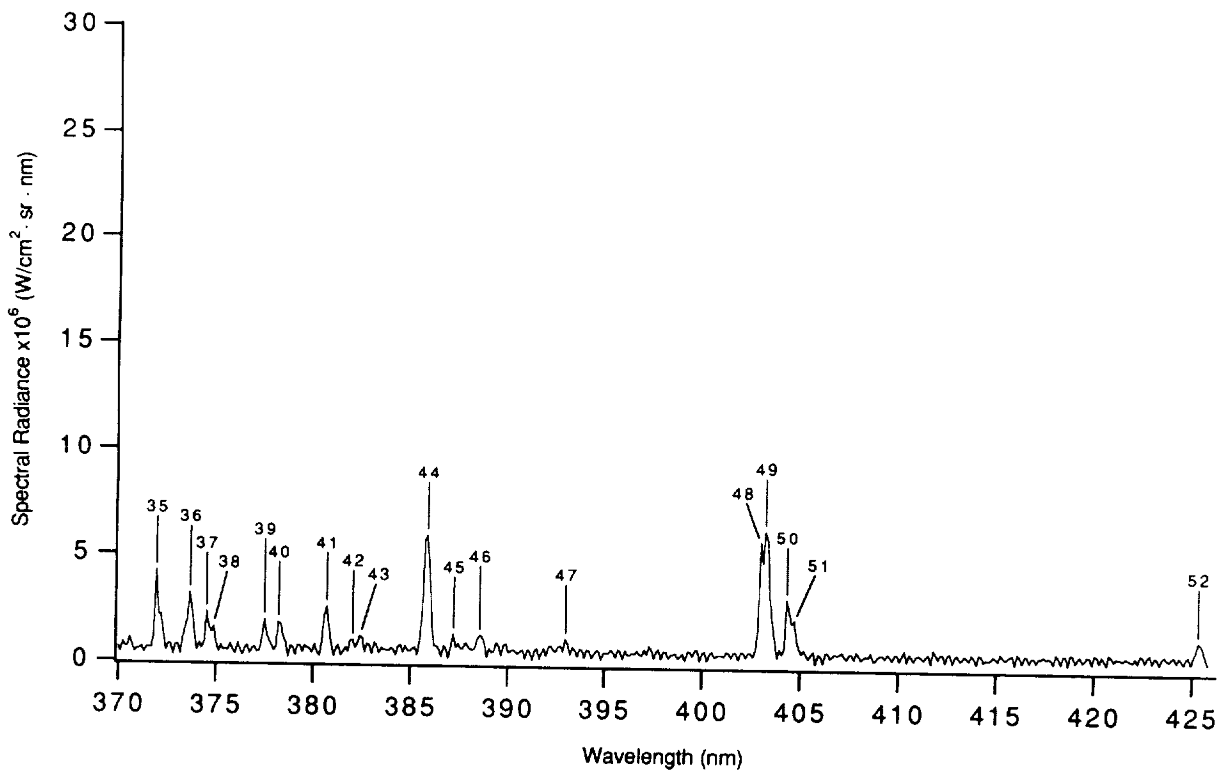

Fig. C-16b. Hastelloy B, 50 ppm; DTFT Plume Spectrum, 370 to 426 nm.

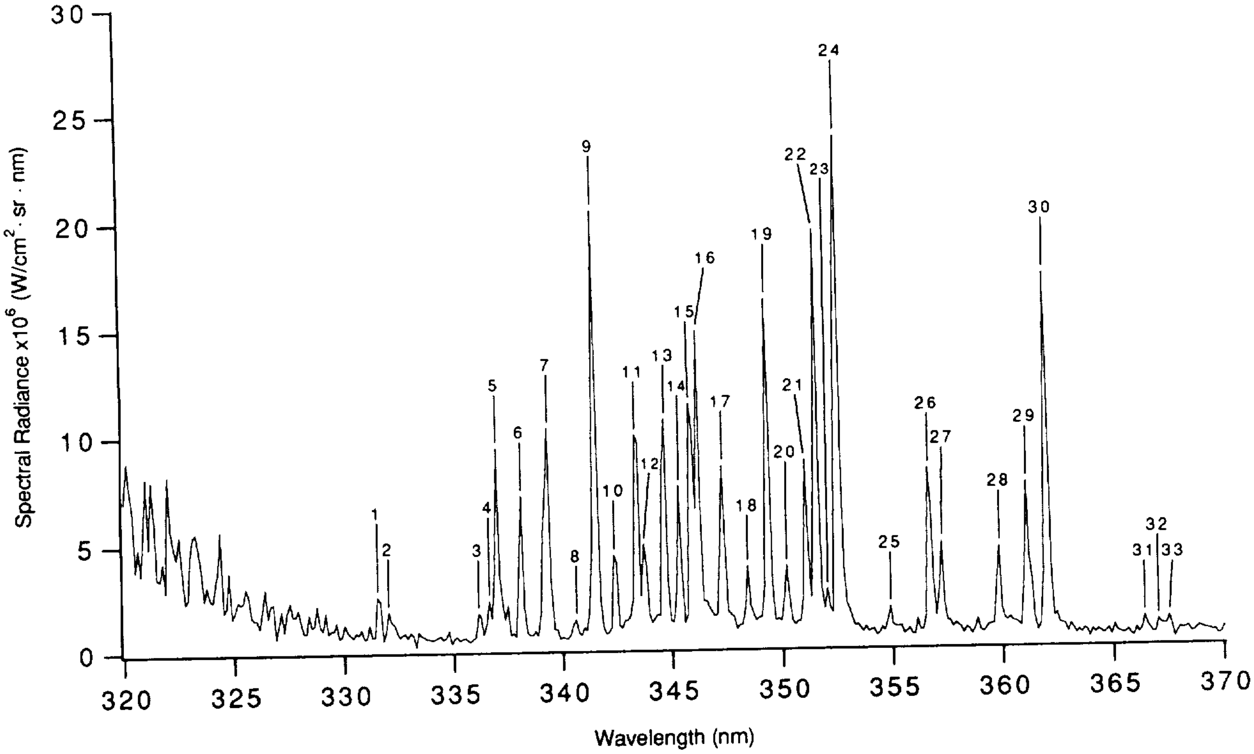

Fig. C-17a. Hastelloy B-2, 50 ppm; DTFT Plume Spectrum, 320 to 370 nm.

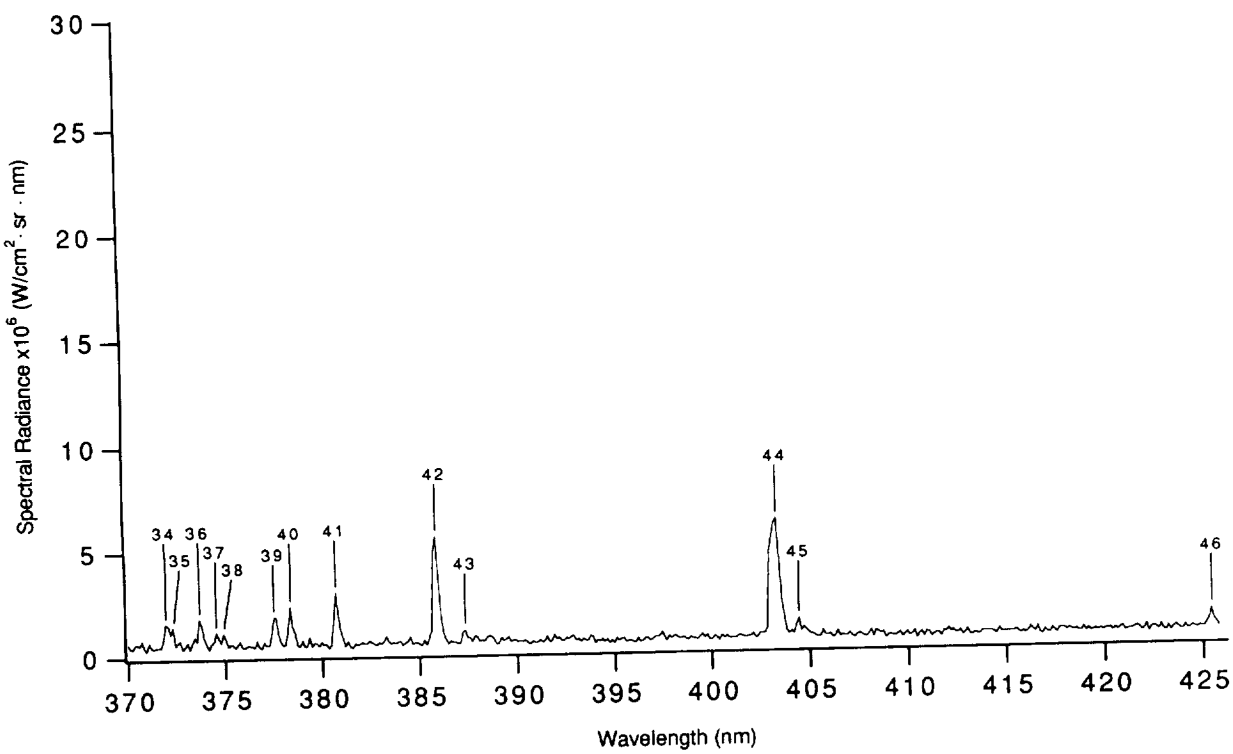

Fig. C-17b. Hastelloy B-2, 50 ppm; DTFT Plume Spectrum, 370 to 426 nm.

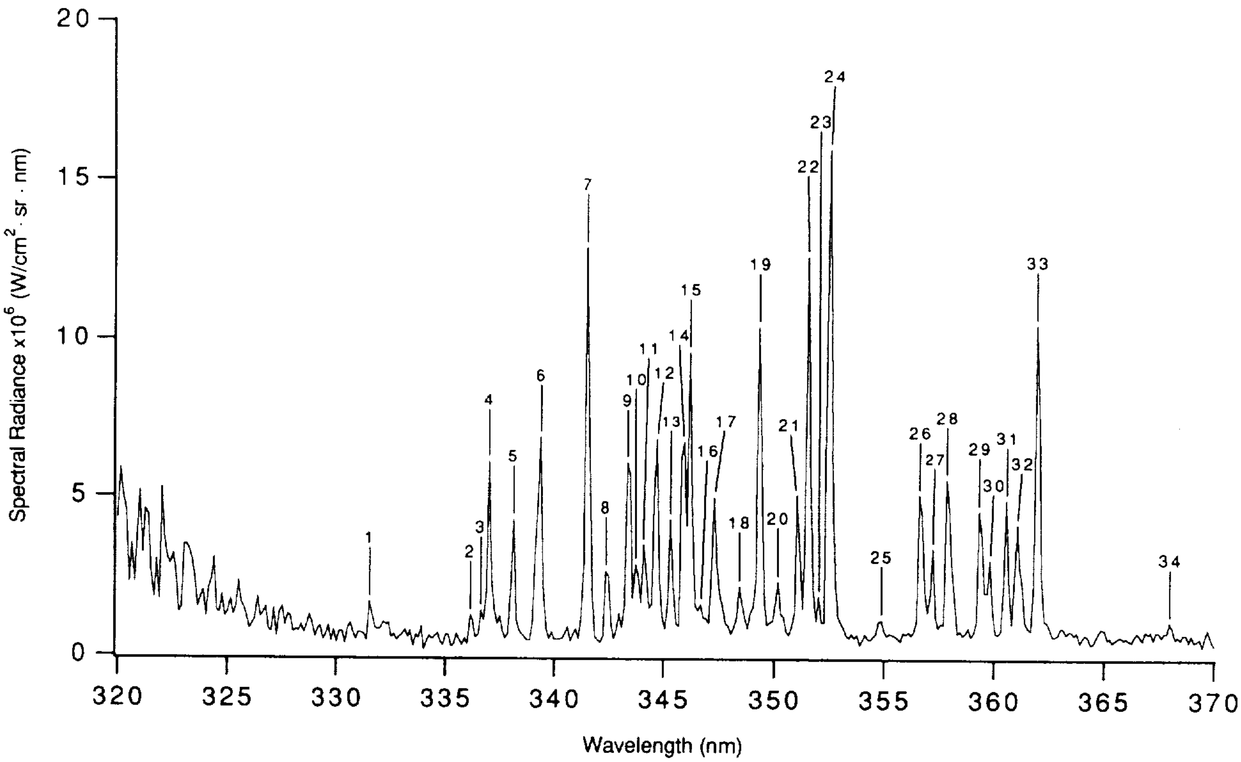

Fig. C-18a. Hastelloy X, 50 ppm; DTFT Plume Spectrum, 320 to 370 nm.

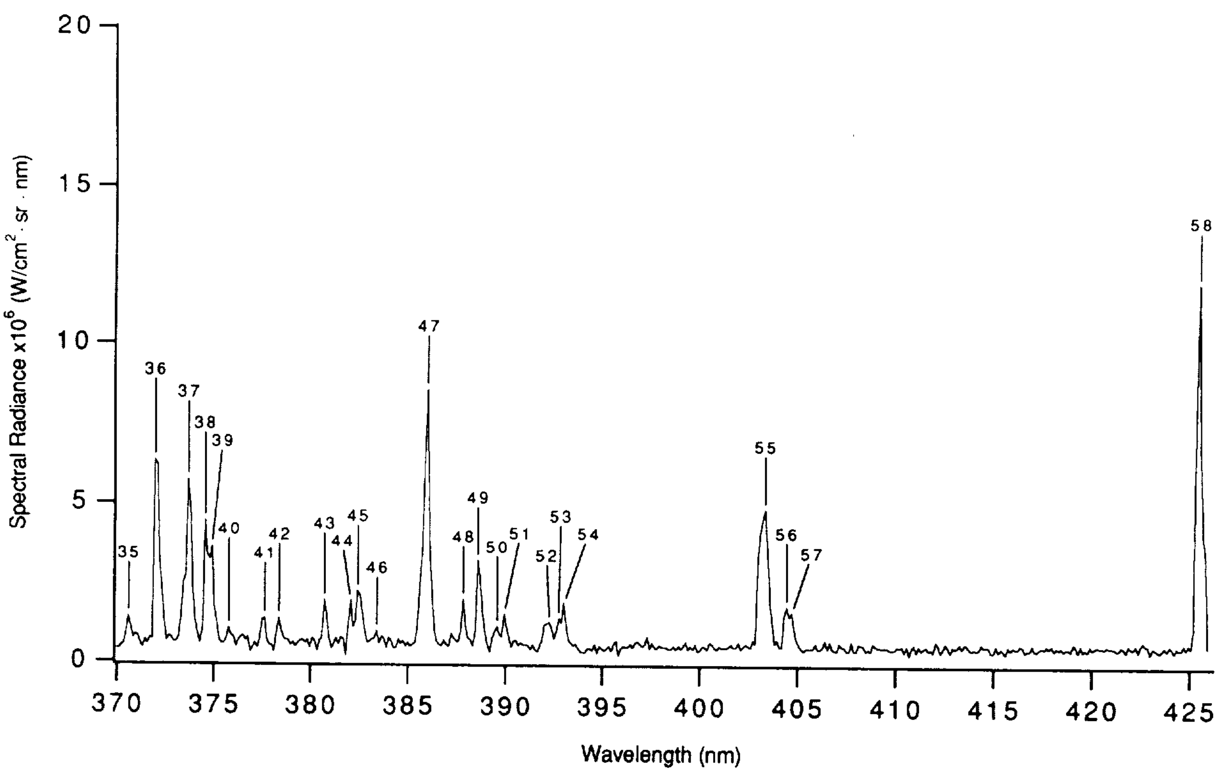

Fig. C-18b. Hastelloy X, 50 ppm; DTFT Plume Spectrum, 370 to 426 nm.

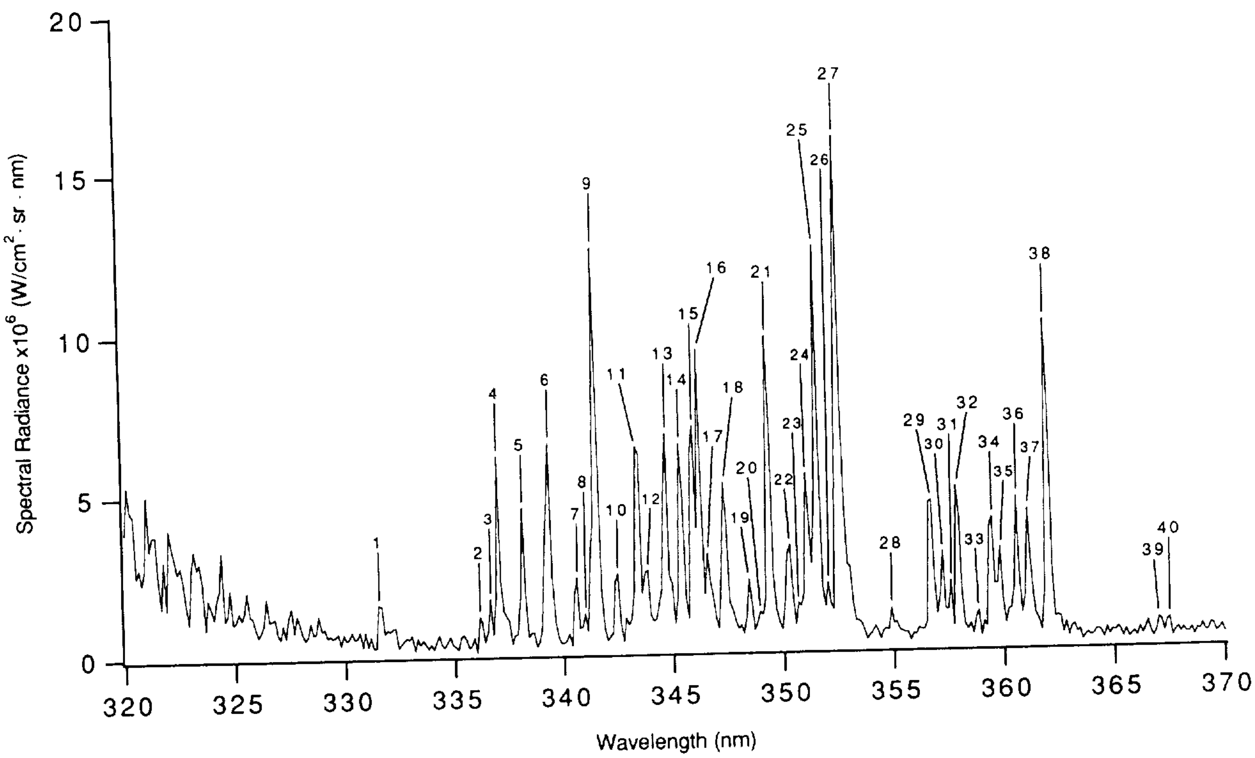

Fig. C-19a. Rene 41, 50 ppm; DTFT Plume Spectrum, 320 to 370 nm.

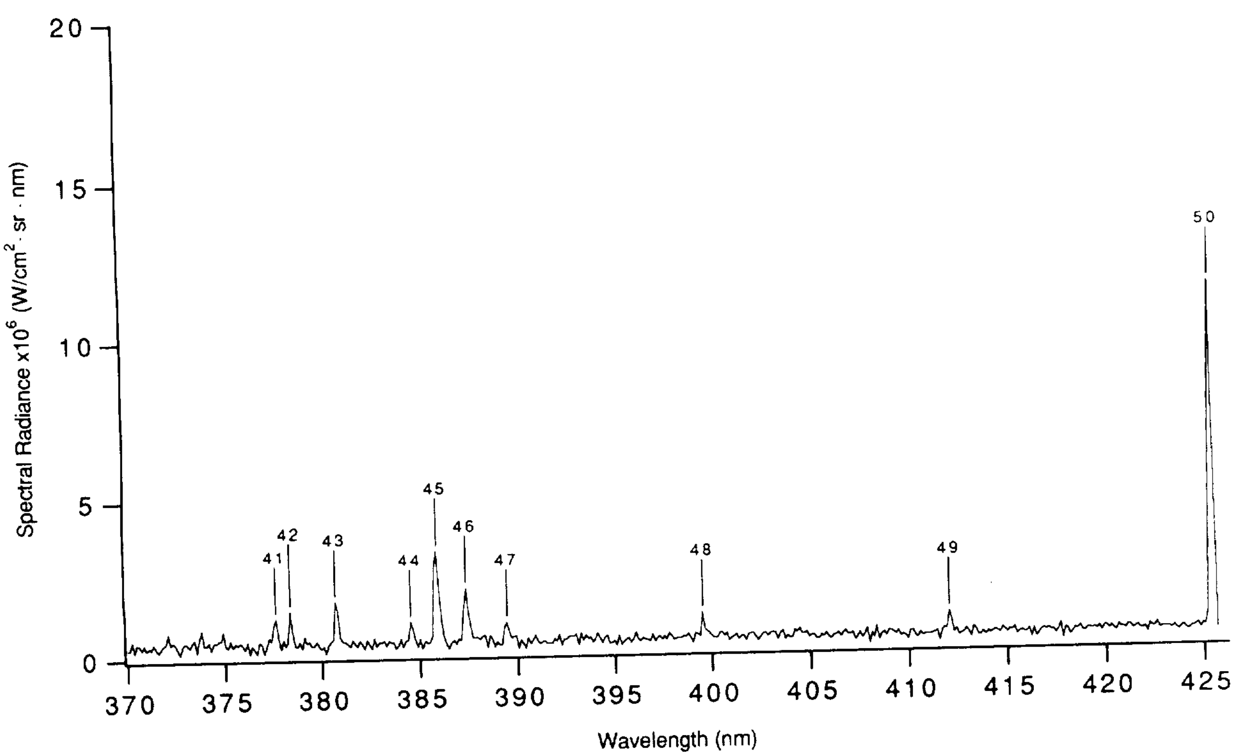

Fig. C-19b. Rene 41, 50 ppm; DTFT Plume Spectrum, 370 to 426 nm.

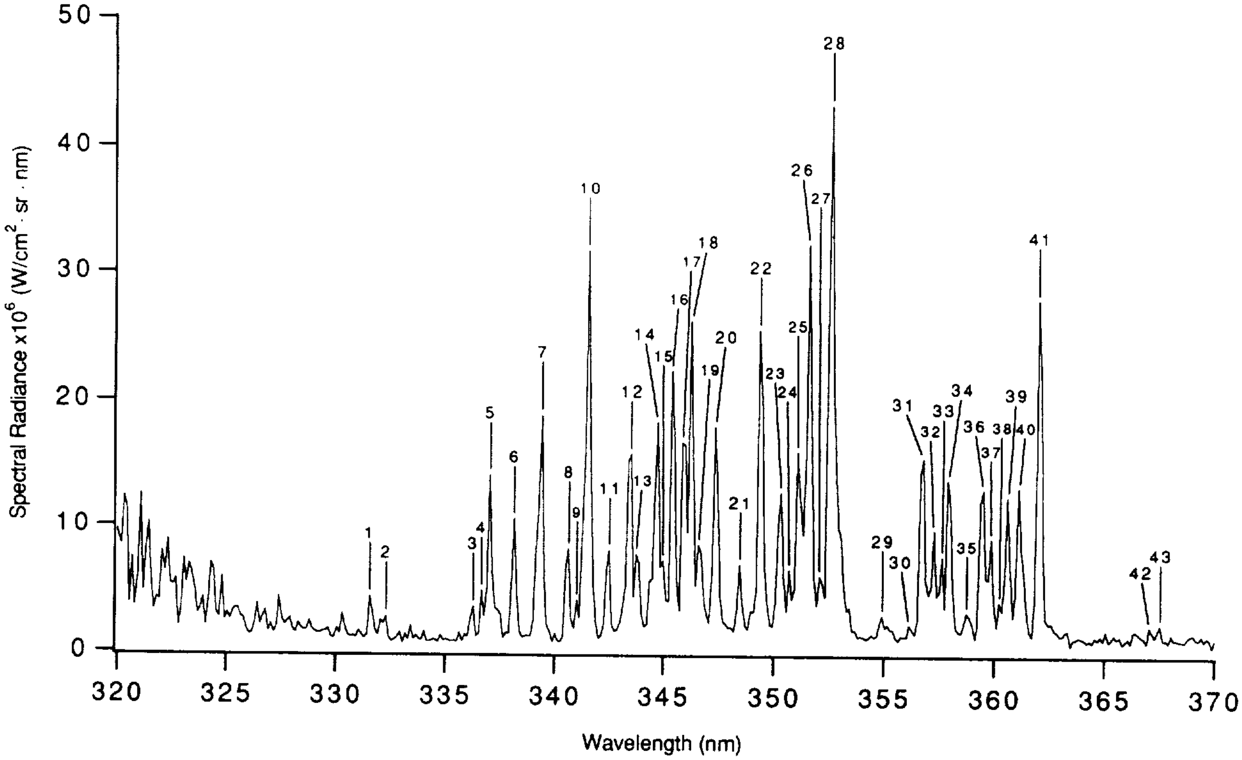

Fig. C-20a. Waspaloy, 50 ppm; DTFT Plume Spectrum, 320 to 370 nm.

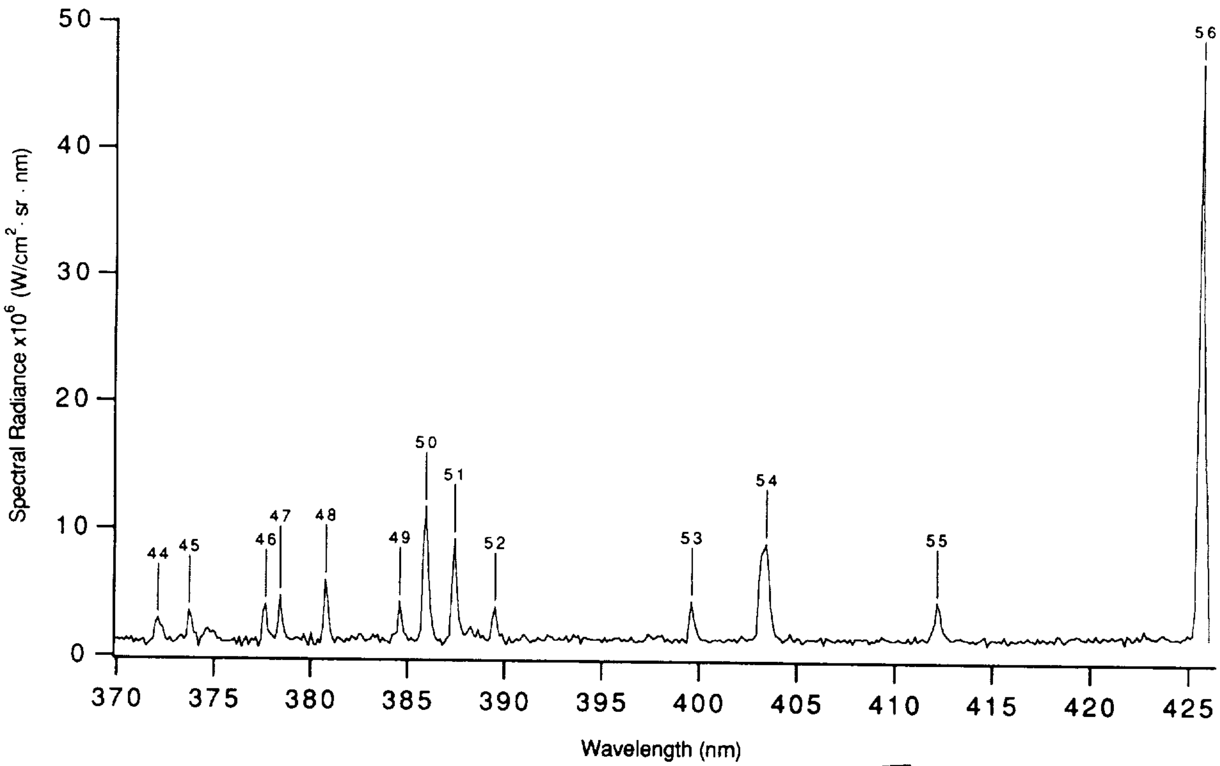

Fig. C-20b. Waspaloy, 50 ppm; DTFT Plume Spectrum, 370 to 426 nm.

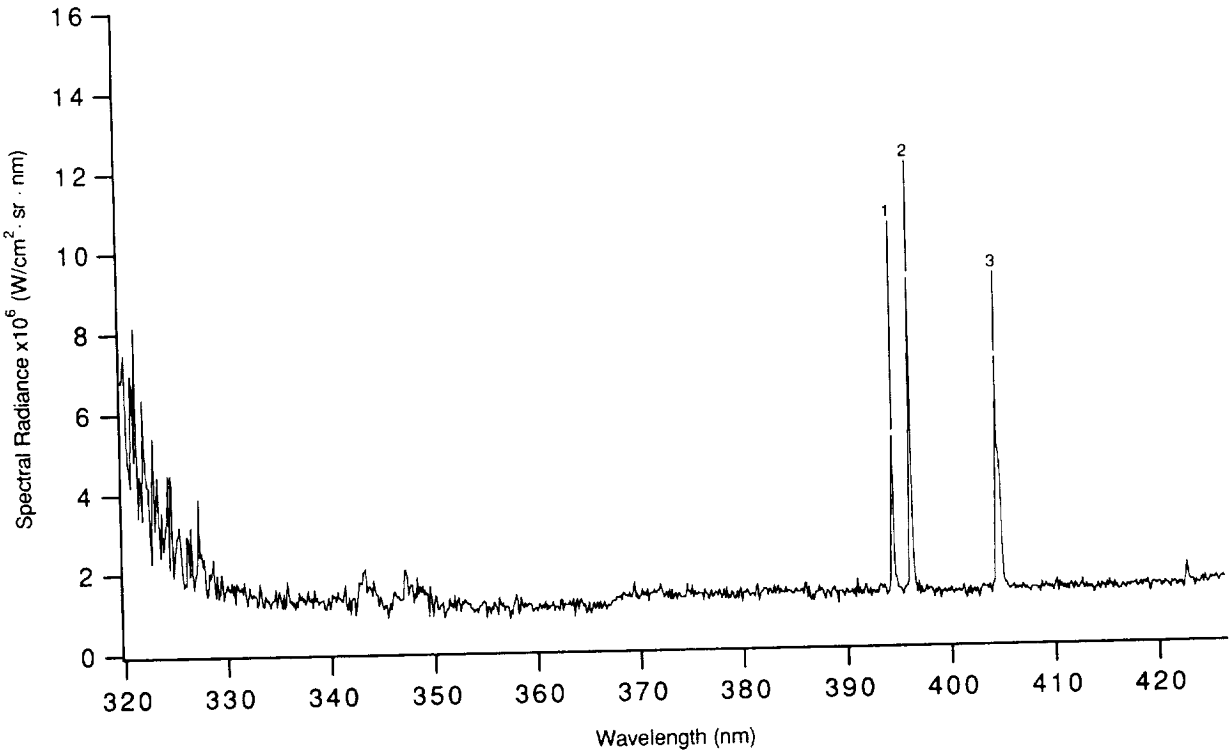

Fig. C-21. Tens-50 Aluminum, 100 ppm; DTFT Plume Spectrum, 320 to 426 nm.

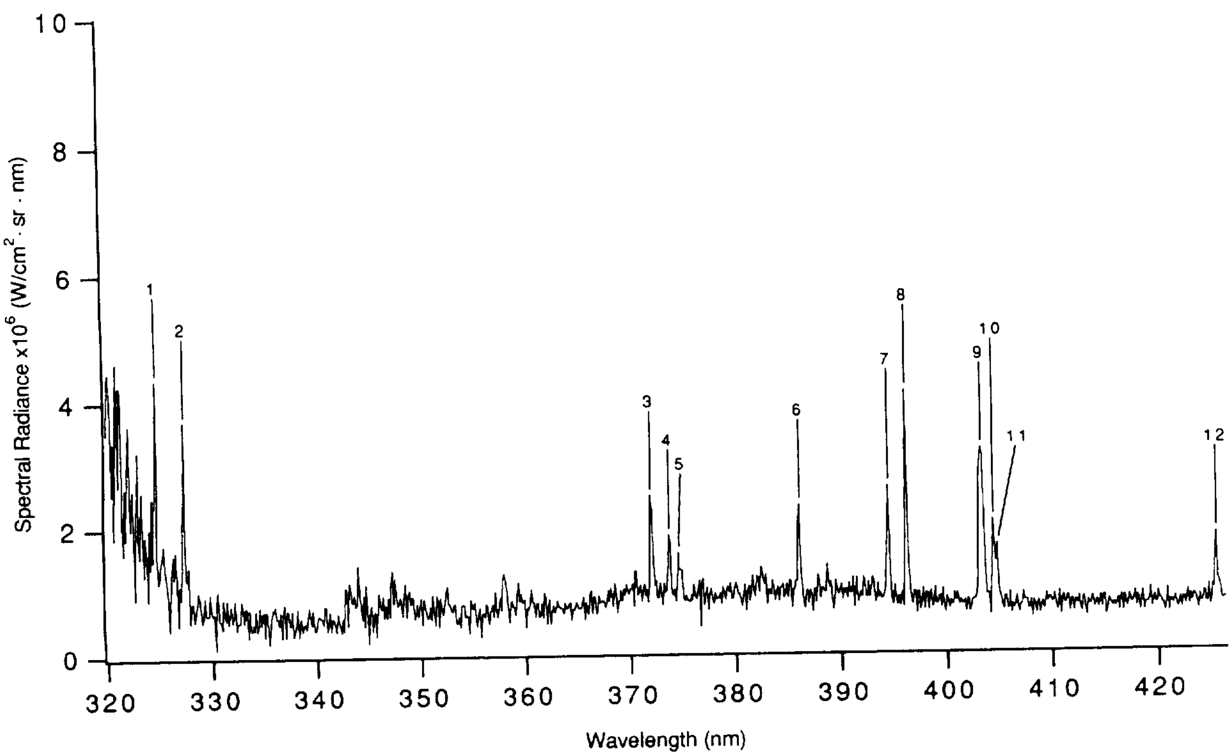

Fig. C-22. 6061 Aluminum, 100 ppm; DTFT Plume Spectrum, 320 to 426 nm.

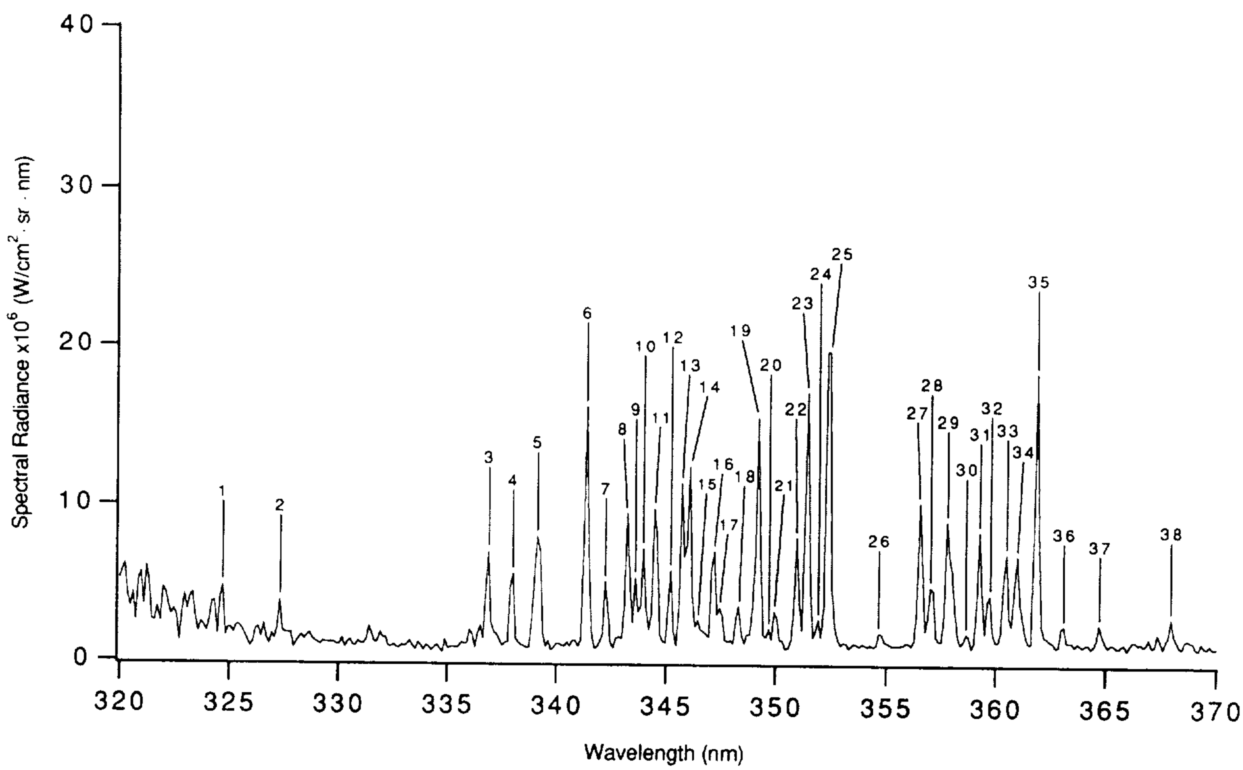

Fig. C-23a. Incoloy 88, 50 ppm; DTFT Plume Spectrum, 320 to 370 nm.

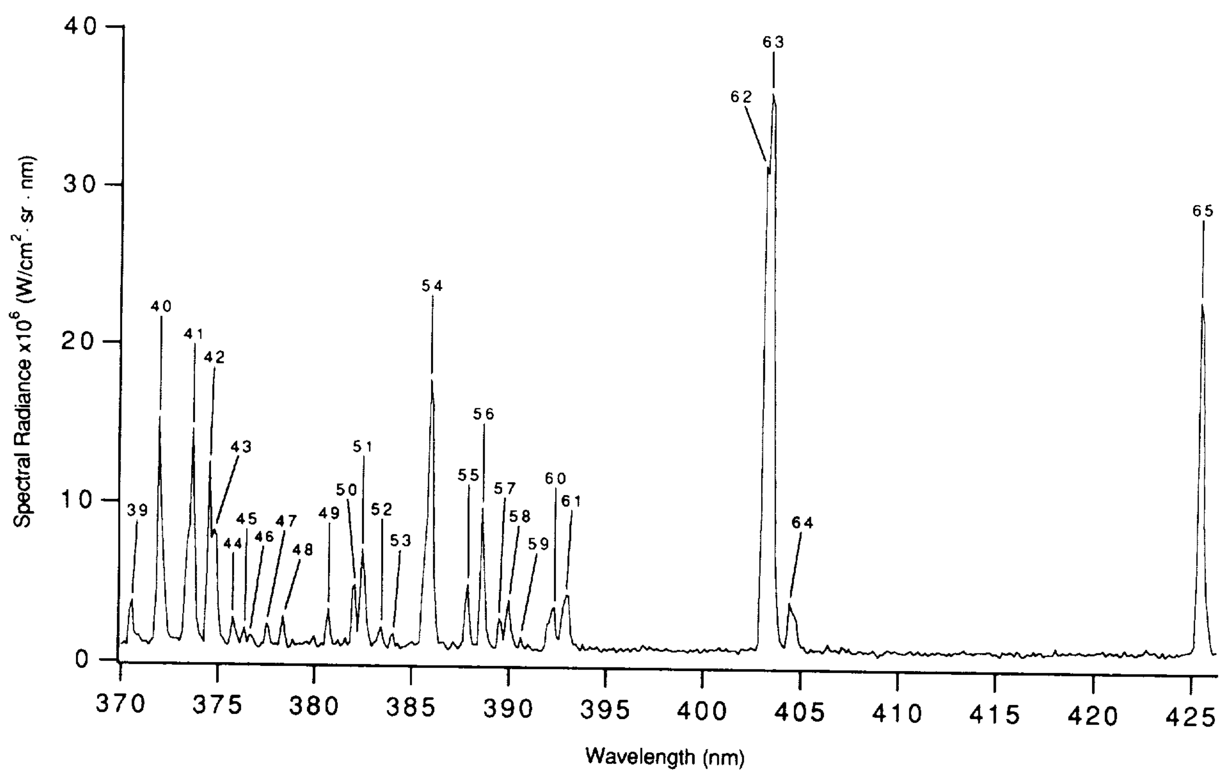

Fig. C-23b. Incoloy 88, 50 ppm; DTFT Plume Spectrum, 370 to 426 nm.

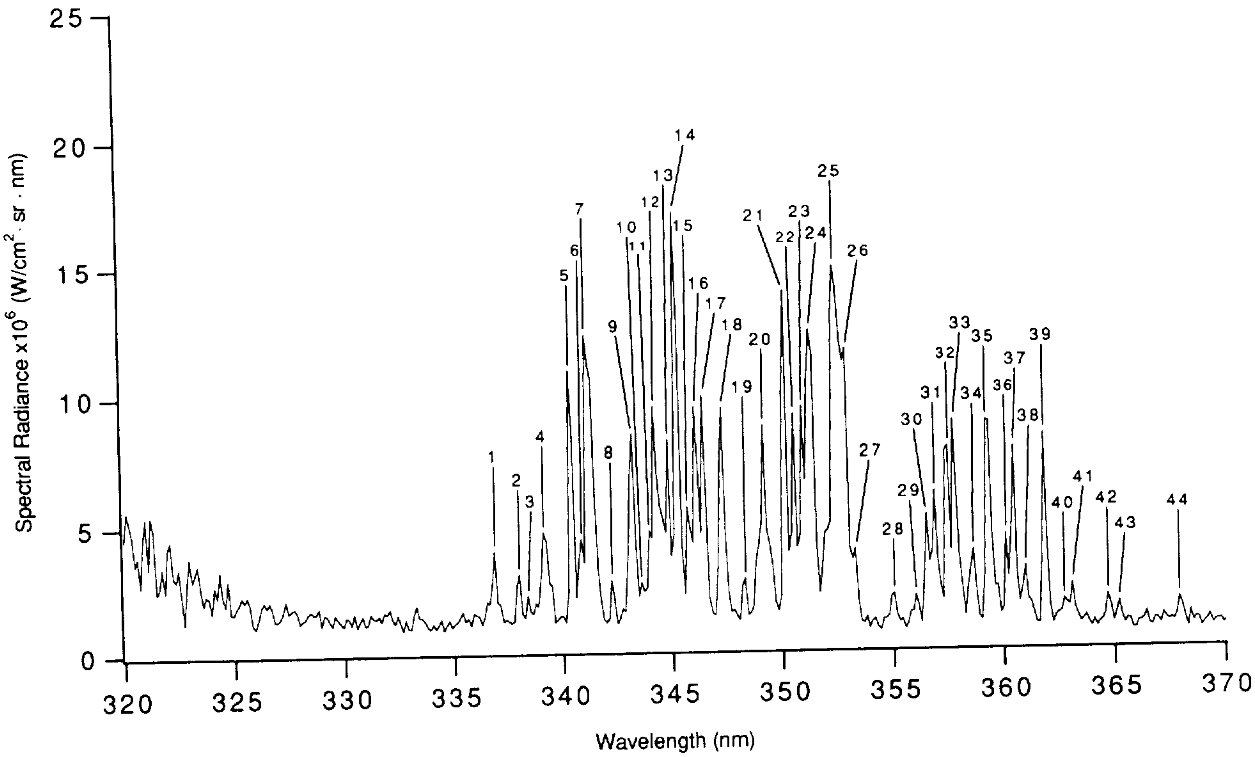

Fig. C-24a. Elgiloy, 50 ppm; DTFT Plume Spectrum, 320 to 370 nm.

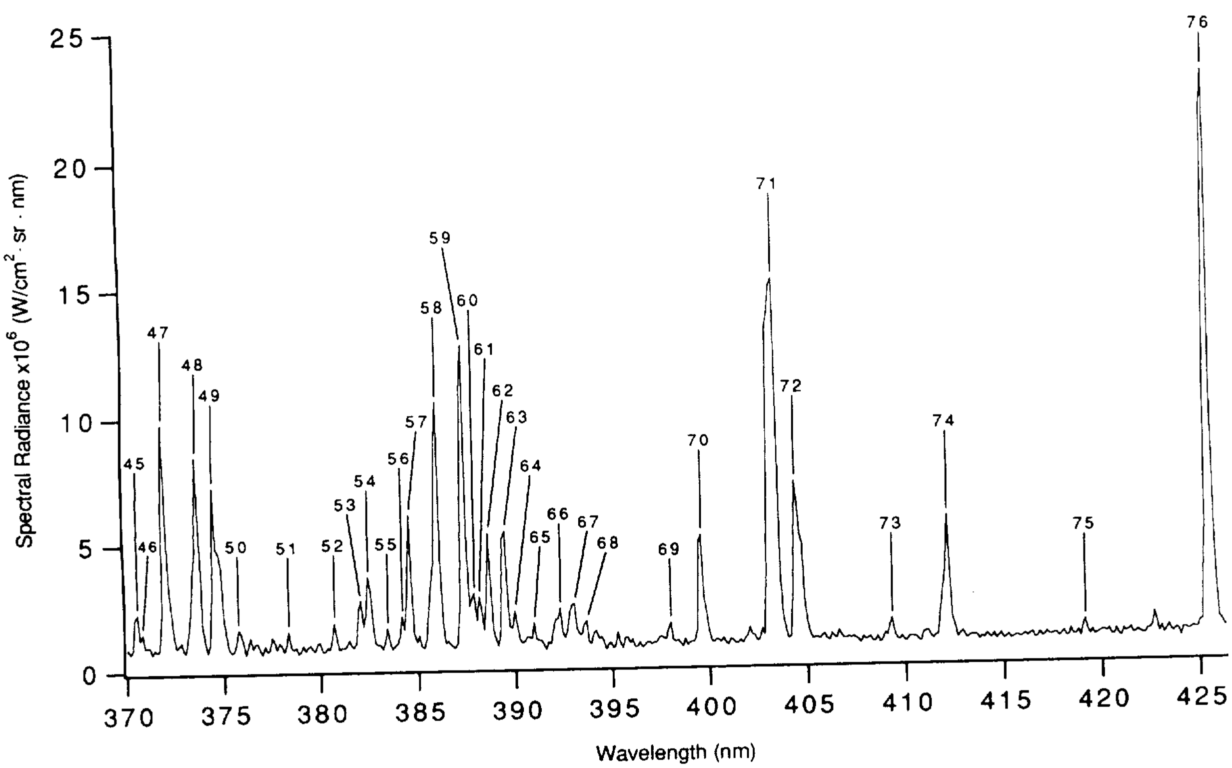

Fig. C-24b. Elgiloy, 50 ppm; DTFT Plume Spectrum, 370 to 426 nm.

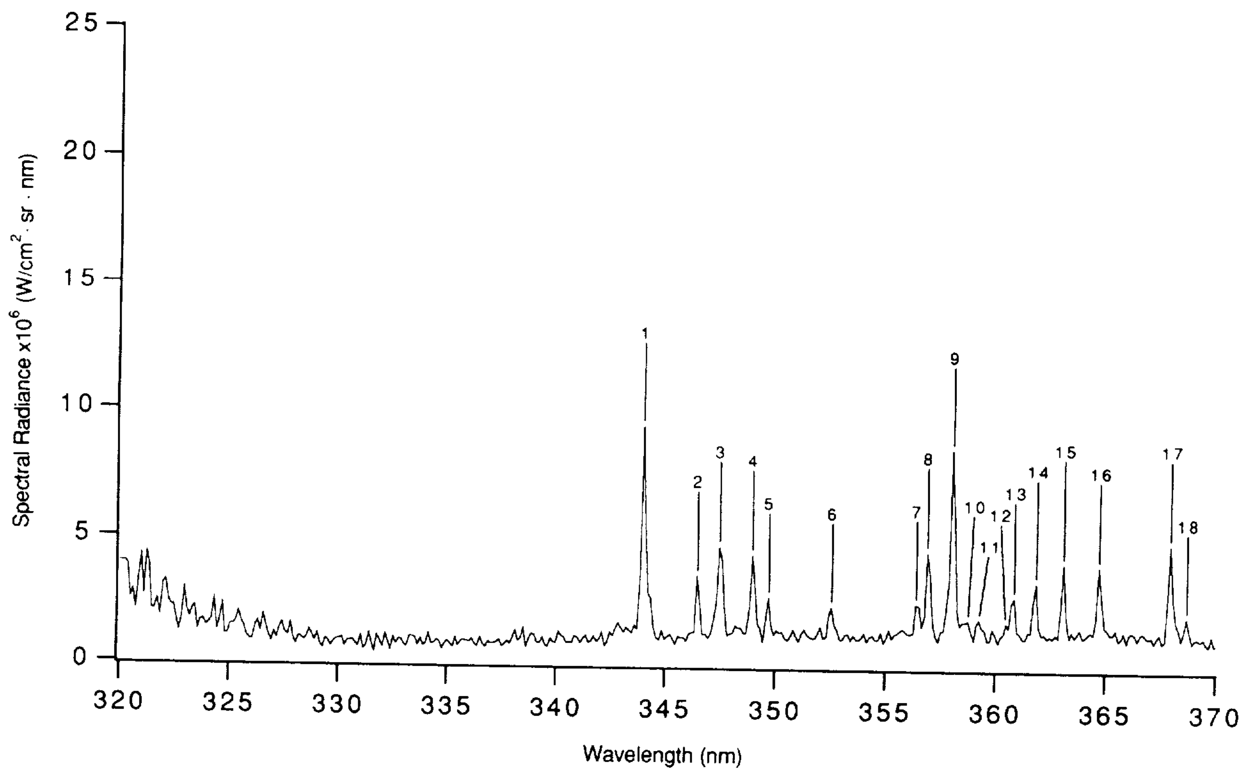

Fig. C-25a. Nitriding Steel, 50 ppm; DTFT Plume Spectrum, 320 to 370 nm.

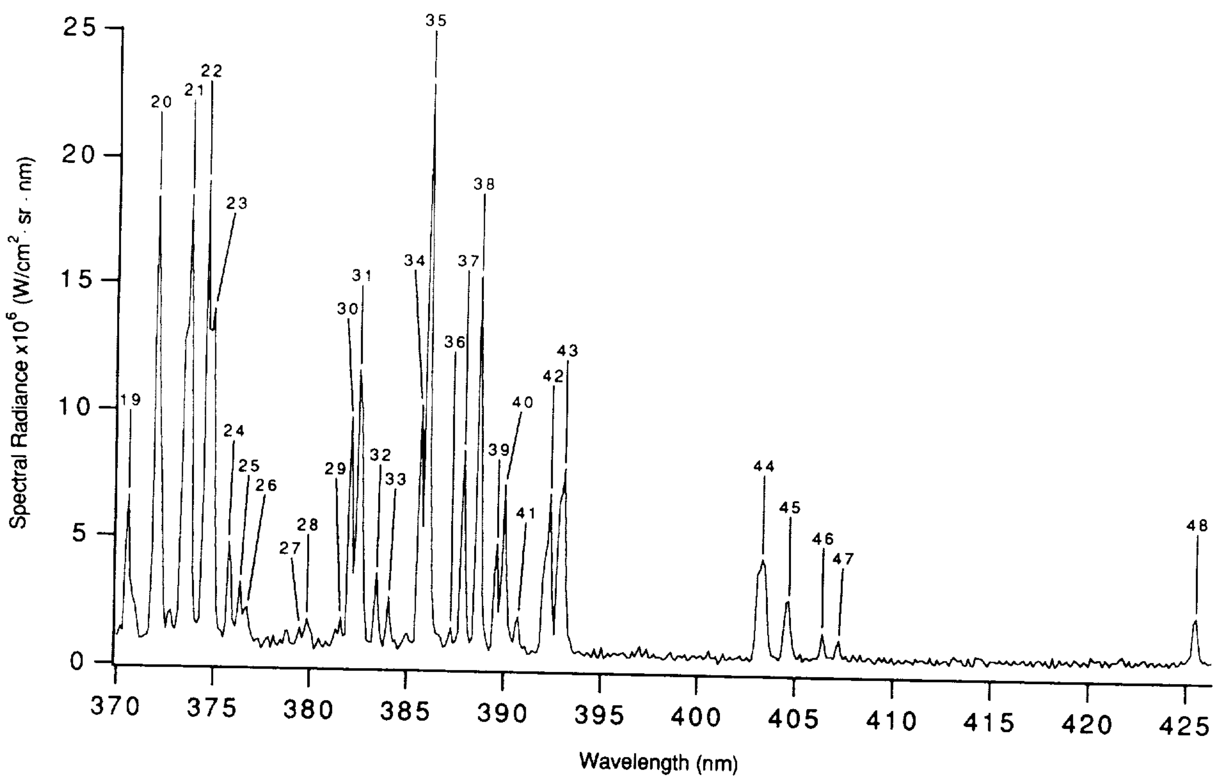

Fig. C-25b. Nitriding Steel, 50 ppm; DTFT Plume Spectrum, 370 to 426 nm.

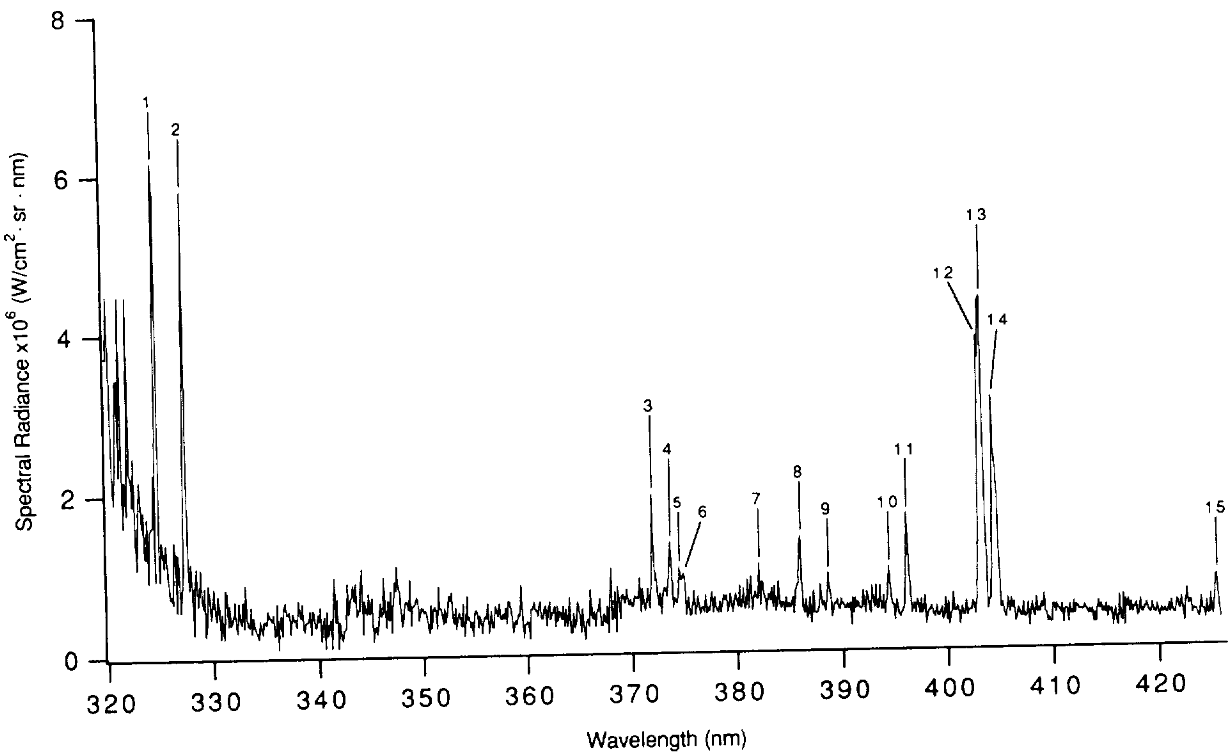

Fig. C-26. 2024 Aluminum, 100 ppm; DTFT Plume Spectrum, 320 to 426 nm.

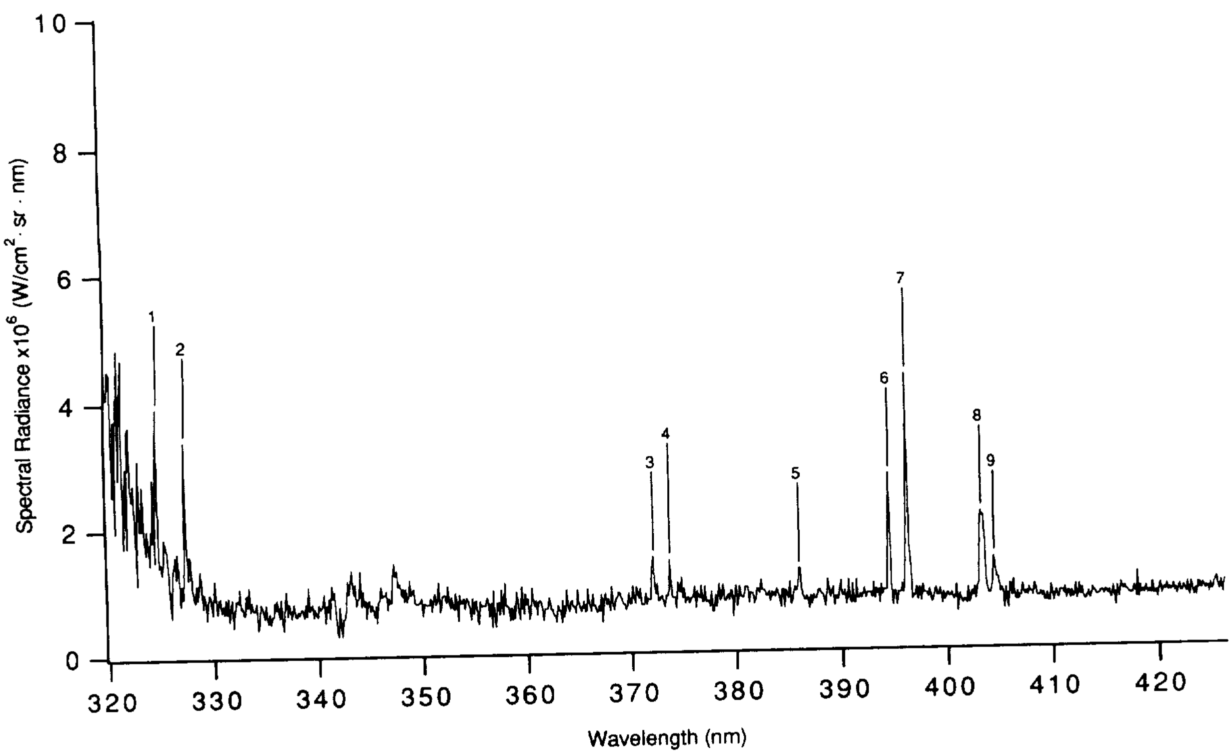

Fig. C-27. A356 Aluminum, 100 ppm; DTFT Plume Spectrum, 320 to 426 nm.

Table C-1. Spectral Lines of DTFT Exhaust Plume Doped with 50 ppm Inconel 718.

Peak No.	Wavelength (in nm)	Emitter	Contributing Lines (Wavelength in nm)	References
1	331.55	Ni	331.57	A, F, M, R
2	332.05	Ni	332.03	A, M, R
3	332.30	Ni	332.23	A, M, R
4	336.16	Ni	336.16	A, F, M, R
5	336.66	Ni	336.62, 336.58	A, F, M, R
6	337.03	Ni	336.96, 337.20	A, M, R
		Fe	337.08, 336.96	M
7	338.15	Ni	338.06, 338.09	A, F, M, R
8	339.39	Ni	339.30, 339.11	A, F, M, R
9	341.51	Ni	341.48, 341.39, 341.35	A, M, R
10	342.38	Ni	342.37	A, F, M, R
11	343.38	Ni	343.36	A, F, M, R
12	343.75	Ni	343.73	A, F, M, R
13	344.12	Fe	344.06, 344.10	A, F, M, R
14	344.74	Ni	344.63	A, F, M, R
15	345.36	Ni	345.29	A, F, M, R
16	345.86	Ni	345.85	A, F, M, R
17	346.23	Ni	346.17	A, F, M, R
18	346.73	Fe	346.59	A, F, M, R
		Ni	346.75	A, M, R
19	347.35	Ni	347.25	A, F, M, R
20	348.47	Ni	348.38, 348.59	A, F, M, R
21	349.34	Ni	349.30	A, F, M, R
22	349.83	Fe	349.78	A, F, M, R
23	350.20	Ni	350.09	A, F, M, R
24	351.07	Ni	351.03	A, F, M, R
25	351.57	Ni	351.51	A, F, M, R
26	352.07	Ni	351.98	A, F, M, R
27	352.56	Ni	352.45	A, F, M, R
		Fe	352.60, 352.62	A, F, M, R
28	354.92	Ni	354.82	A, F, M, R
29	356.65	Ni	356.64	A, F, M, R
		Fe	356.54	A, F, M, R
30	357.27	Ni	357.19	A, F, M, R
		Fe	357.01, 357.03	M, R
31	357.89	Cr	357.87	A, F, M, R

Table C-1. Spectral Lines of DTFT Exhaust Plume Doped with 50 ppm Inconel 718 (continued).

Peak No.	Wavelength (in nm)	Emitter	Contributing Lines (Wavelength in nm)	References
32	358.88	Ni	358.79	A, M, R
		Fe	358.70, 358.61	M, R
33	359.38	Cr	359.35	A, F, M, R
34	359.87	Ni	359.77	A, F, M, R
35	360.62	Cr	360.53	A, F, M, R
36	361.11	Ni	361.05, 361.27	A, F, M, R
		Fe	360.89, 361.02	M, R
37	361.98	Ni	361.94	A, F, M, R
		Fe	361.88	A, F, M, R
38	362.47	Ni	362.47	A, M, R
39	363.21	Fe	363.15	A, F, M, R
40	364.82	Fe	364.78, 364.95	M, R
41	366.43	Ni	366.41	A, M, R
42	367.17	Ni	367.04	A, M, R
43	367.42	Ni	367.41	A, M, R
44	368.04	Fe	367.99, 368.22	M, R
45	368.78	Fe	368.75, 368.60	M, R
46	370.63	Fe	370.56, 370.79, 370.78	M, R
47	372.12	Fe	371.99, 372.26	A, F, M, R
		Ni	372.25	A, M, R
48	373.72	Fe	373.71, 373.49, 373.33	A, F, M, R
		Ni	373.68	A, M, R
49	374.59	Fe	374.56, 374.59	A, F, M, R
50	374.96	Fe	374.95, 374.83	A, F, M, R
51	375.82	Fe	375.82, 376.00	M, R
52	376.44	Fe	376.38, 376.55	F, M, R
53	377.55	Ni	377.56	A, F, M, R
54	378.41	Ni	378.35	A, F, M, R
55	380.76	Ni	380.71	A, F, M, R
56	382.11	Fe	382.04, 382.12	M, R
57	382.48	Fe	382.44, 382.59	A, F, M, R
58	383.47	Fe	383.42	A, F, M, R
		Ni	383.17	A, M, R
59	386.06	Fe	385.99	A, F, M, R
		Ni	385.83	A, F, M, R
60	387.91	Fe	387.86, 387.80	A, F, M, R
61	388.65	Fe	388.63, 388.70	A, F, M, R

Table C-1. Spectral Lines of DTFT Exhaust Plume Doped with 50 ppm Inconel 718 (continued).

Peak No.	Wavelength (in nm)	Emitter	Contributing Lines (Wavelength in nm)	References
62	389.63	Fe	389.57	A, F, M, R
63	390.00	Fe	389.97, 390.29	A, F, M, R
64	392.35	Fe	392.29, 392.03	A, F, M, R
65	392.84	Fe	392.79	A, F, M, R
66	393.08	Fe	393.03	A, F, M, R
67	403.42	Mn	403.08, 403.31, 403.45	A, F, M, R
68	404.65	Fe	404.58	A, F, M, R
		K	404.41, 404.72	A, F, M, R
69	425.56	Cr	425.43	A, F, M, R

Table C-2. Spectral Lines of DTFT Exhaust Plume Doped with 50 ppm Haynes 188.

Peak No.	Wavelength (in nm)	Emitter	Contributing Lines (Wavelength in nm)	References
1	336.66	Ni	336.62, 336.58	A, F, M, R
2	337.03	Ni	336.96, 337.20	A, M, R
3	338.15	Ni	338.06, 338.09	A, F, M, R
4	338.52	Co	338.52	A, F, M
5	339.39	Ni	339.30, 339.11	A, F, M, R
		Co	339.54	A, F, M, R
6	340.64	Co	340.51	A, F, M, R
7	341.01	Co	340.92	A, F, M, R
8	341.51	Co	341.23, 341.26, 341.72	A, F, M, R
		Ni	341.48, 341.39, 341.35	A, M, R
9	342.50	Ni	342.37	A, F, M, R
10	343.38	Co	343.30, 343.16	A, F, M, R
		Ni	343.36	A, F, M, R
11	343.75	Ni	343.73	A, F, M, R
12	344.37	Co	344.36, 344.29	A, F, M, R
		Fe	344.06, 344.10, 344.39	A, F, M, R
13	344.74	Ni	344.63	A, F, M, R
14	344.99	Co	344.92, 344.94	A, F, M, R
15	345.36	Co	345.35, 345.52	A, F, M, R
		Ni	345.29	A, F, M, R
16	345.86	Ni	345.85	A, F, M, R
17	346.23	Ni	346.17	A, F, M, R
		Co	346.28	A, F, M, R
18	346.61	Co	346.58	A, F, M, R
		Fe	346.59	A, F, M, R
19	347.47	Co	347.40	A, F, M, R
		Ni	347.25	A, F, M, R
		Fe	347.55, 347.67, 347.65	A, R
20	348.47	Ni	348.38, 348.59	A, F, M, R
		Co	348.34	A, F, M, R
21	348.96	Co	348.94	A, F, M, R
		Fe	349.06	A, F, M, R
22	349.34	Ni	349.30	A, F, M, R
		Co	349.57	A, F, M, R
23	350.33	Co	350.23	A, F, M, R
		Ni	350.09	A, F, M, R
24	350.70	Co	350.63	A, F, M, R
25	351.07	Co	350.98, 351.04	A, F, M, R
		Ni	351.03	A, F, M, R
26	351.57	Ni	351.51	A, F, M, R
		Co	351.26, 351.35	A, F, M, R

Table C-2. Spectral Lines of DTFT Exhaust Plume Doped with 50 ppm Haynes 188 (continued).

Peak No.	Wavelength (in nm)	Emitter	Contributing Lines (Wavelength in nm)	References
27	352.19	Co	352.16, 352.01, 352.34	A, M, R
28	352.56	Ni	352.45	A, F, M, R
		Co	352.68	A, F, M, R
		Fe	352.60, 352.62	A, F, M, R
29	353.06	Co	352.98, 352.90	A, F, M, R
30	353.43	Co	353.34	A, F, M, R
31	355.17	Co	355.06	A, F, M
32	356.16	Co	356.09	A, F, M, R
33	356.65	Ni	356.64	A, F, M, R
		Co	356.50	A, F, M
		Fe	356.54	A, F, M, R
34	357.02	Co	356.94	A, F, M, R
		Ni	357.19	A, F, M, R
		Fe	357.01, 357.03	M, R
35	357.64	Co	357.54, 357.50	A, F, M, R
36	357.89	Cr	357.87	A, F, M, R
37	358.76	Co	358.72, 358.52	A, F, M, R
38	359.50	Cr	359.35	A, F, M, R
		Co	359.49	A, F, M, R
39	359.87	Ni	359.77	A, F, M, R
40	360.24	Co	360.21	A, F, M, R
41	360.62	Cr	360.53	A, F, M, R
42	361.11	Ni	361.05, 361.27	A, F, M, R
		Fe	360.89, 361.02	M, R
43	361.98	Ni	361.94	A, F, M, R
		Fe	361.88	A, F, M, R
44	362.84	Co	362.78	A, F, M, R
45	363.21	Co	363.14	A, F, M
		Fe	363.15	A, F, M, R
46	364.82	Co	364.77	A, F, M
		Fe	364.78, 364.95	M, R
47	365.32	Co	365.25	A, F, M
48	370.63	Fe	370.56, 370.79, 370.78	M, R
49	372.12	Fe	371.99, 372.26	A, F, M, R
		Ni	372.25	A, M, R
50	373.72	Fe	373.71, 373.49, 373.33	A, F, M, R
		Ni	373.68	A, M, R
51	374.59	Fe	374.56, 374.59	A, F, M, R
		Co	374.55	A, F, M, R
52	374.96	Fe	374.95, 374.83	A, F, M, R

Table C-2. Spectral Lines of DTFT Exhaust Plume Doped with 50 ppm Haynes 188 (continued).

Peak No.	Wavelength (in nm)	Emitter	Contributing Lines (Wavelength in nm)	References
53	377.67	Ni	377.56	A, F, M, R
54	378.41	Ni	378.35	A, F, M, R
55	380.76	Ni	380.71	A, F, M, R
		Co	380.81	A, M
56	382.11	Fe	382.04, 382.12	M, R
57	382.48	Fe	382.44, 382.59	A, F, M, R
58	384.58	Co	384.55, 384.20	A, F, M, R
59	386.06	Fe	385.99, 385.64	A, F, M, R
		Ni	385.83	A, F, M, R
60	387.42	Co	387.31, 387.40	A, F, M, R
		Fe	387.25, 387.38	M, R
61	388.28	Co	388.19	A, F, M, R
62	388.65	Fe	388.63, 388.70	M, R
63	389.51	Co	389.41, 389.50	A, F, M, R
		Fe	389.57	A, F, M, R
64	391.11	Co	390.99	A, F, M
65	393.70	Co	393.60	A, F, M, R
66	394.19	Co	394.17, 394.09	A, F, M
67	398.01	Co	397.95, 397.87	A, F, M
68	399.61	Co	399.53, 399.79	A, F, M, R
69	402.07	Co	402.09	A, F, M, R
70	403.42	Mn	403.08, 403.31, 403.45	A, F, M, R
71	404.78	K	404.41, 404.72	A, M, R
		Co	404.54	A, F, M, R
72	409.33	Co	409.24	A, F, M, R
73	412.16	Co	412.13, 411.88	A, F, M, R
74	419.29	Co	419.07	A, F, M, R
75	425.56	Cr	425.43	A, F, M, R

Table C-3. Spectral Lines of DTFT Exhaust Plume Doped with 50 ppm MAR-M 246+Hf.

Peak No.	Wavelength (in nm)	Emitter	Contributing Lines (Wavelength in nm)	References
1	331.55	Ni	331.57	A, F, M, R
2	332.05	Ni	332.03	A, M, R
3	332.30	Ni	332.23	A, M, R
4	336.28	Ni	336.16	A, F, M, R
5	336.66	Ni	336.62, 336.58	A, F, M, R
6	337.03	Ni	336.96, 337.20	A, M, R
7	338.15	Ni	338.06, 338.09	A, F, M, R
8	339.39	Ni	339.30, 339.11	A, F, M, R
		Co	339.54	A, F, M, R
9	340.64	Co	340.51	A, F, M, R
10	341.01	Co	340.92	A, F, M, R
		Ni	340.96	A, M, R
11	341.51	Ni	341.48, 341.39, 341.35	A, M, R
		Co	341.23, 341.72, 341.26	A, F, M, R
12	342.50	Ni	342.37	A, F, M, R
13	343.50	Ni	343.36	A, F, M, R
		Co	343.30	A, F, M, R
14	343.75	Ni	343.73	A, F, M, R
15	344.74	Ni	344.63	A, F, M, R
		Co	344.92, 344.94, 344.36, 344.29	A, F, M, R
16	345.36	Co	345.35, 345.52	A, F, M, R
		Ni	345.29	A, F, M, R
17	345.86	Ni	345.85	A, F, M, R
18	346.23	Ni	346.17	A, F, M, R
		Co	346.28	A, F, M, R
19	346.61	Co	346.58	A, F, M, R
		Ni	346.75	A, M, R
20	347.35	Ni	347.25	A, F, M, R
		Co	347.40	A, F, M, R
21	348.47	Ni	348.38, 348.59	A, F, M, R
		Co	348.34	A, F, M, R
22	348.96	Co	348.94	A, F, M, R
23	349.34	Ni	349.30	A, F, M, R
		Co	349.57	A, F, M, R
24	350.20	Co	350.23	A, F, M, R
		Ni	350.09	A, F, M, R
25	350.70	Co	350.63	A, F, M, R
26	351.07	Ni	351.03	A, F, M, R
		Co	350.98, 351.04	A, F, M, R

Table C-3. Spectral Lines of DTFT Exhaust Plume Doped with 50 ppm MAR-M 246+Hf (continued).

Peak No.	Wavelength (in nm)	Emitter	Contributing Lines (Wavelength in nm)	References
27	351.57	Ni	351.51	A, F, M, R
		Co	351.26, 351.35	A, F, M, R
28	352.07	Co	352.16, 352.01	A, F, M, R
		Ni	351.98	A, F, M, R
29	352.56	Ni	352.45	A, F, M, R
		Co	352.68, 352.90	A, F, M, R
30	354.92	Ni	354.82	A, F, M, R
31	355.17	Co	355.06	A, F, M
32	356.16	Co	356.09	A, F, M, R
33	356.78	Ni	356.64	A, F, M, R
34	357.27	Ni	357.19	A, F, M, R
35	357.64	Co	357.54, 357.50	A, F, M, R
36	357.89	Cr	357.87	A, F, M, R
37	358.88	Ni	358.79	A, M, R
		Co	358.72	A, F, M, R
38	359.50	Cr	359.35	A, F, M, R
		Co	359.49	A, F, M, R
39	359.87	Ni	359.77	A, F, M, R
40	360.24	Co	360.21	A, F, M, R
41	360.62	Cr	360.53	A, F, M, R
42	361.11	Ni	361.05, 361.27	A, F, M, R
43	361.98	Ni	361.94	A, F, M, R
44	366.55	Ni	366.41	A, M, R
45	367.17	Ni	367.04	A, M, R
46	367.54	Ni	367.41	A, M, R
47	372.36	Ni	372.25	A, M, R
48	373.72	Ni	373.68	A, M, R
49	377.67	Ni	377.56	A, M, R
50	378.41	Ni	378.35	A, F, M, R
51	380.76	Ni	380.71	A, F, M, R
52	383.22	Ni	383.17	A, M, R
53	384.58	Co	384.55, 384.20	A, F, M, R
54	385.94	Ni	385.83	A, F, M, R
55	387.42	Co	387.31, 387.40	A, F, M, R
56	388.28	Co	388.19	A, F, M, R
57	389.51	Co	389.41, 389.50	A, F, M, R

Table C-3. Spectral Lines of DTFT Exhaust Plume Doped with 50 ppm MAR-M 246+Hf (continued).

Peak No.	Wavelength (in nm)	Emitter	Contributing Lines (Wavelength in nm)	References
58	399.61	Co	399.53, 399.79	A, F, M, R
59	412.16	Co	412.13, 411.88	A, F, M, R
60	425.56	Cr	425.43	A, F, M, R

Table C-4. Spectral Lines of DTFT Exhaust Plume Doped with 50 ppm Waspaloy X.

Peak No.	Wavelength (in nm)	Emitter	Contributing Lines (Wavelength in nm)	References
1	331.52	Ni	331.57	A, F, M, R
2	332.27	Ni	332.03, 332.23	A, M, R
3	336.14	Ni	336.16	A, F, M, R
4	336.63	Ni	336.62, 336.58	A, F, M, R
		Co	336.71	A, F, M
5	337.01	Ni	336.96, 337.20	A, M, R
6	338.13	Ni	338.06, 338.09	A, F, M, R
7	339.37	Ni	339.30, 339.11	A, F, M, R
		Co	339.54	A, F, M, R
8	340.61	Co	340.51	A, F, M, R
9	340.99	Co	340.92	A, F, M, R
		Ni	340.96	A, M, R
10	341.49	Ni	341.48, 341.39, 341.35	A, M, R
		Co	341.23, 341.26	A, F, M, R
11	342.48	Ni	342.37	A, F, M, R
12	343.35	Ni	343.36	A, F, M, R
		Co	343.30, 343.16	A, F, M, R
13	343.72	Ni	343.73	A, F, M, R
14	344.72	Ni	344.63	A, F, M, R
		Co	344.92, 344.94	A, F, M, R
15	345.34	Co	345.35, 345.52	A, F, M, R
		Ni	345.29	A, F, M, R
16	345.83	Ni	345.85	A, F, M, R
17	346.21	Ni	346.17	A, F, M, R
		Co	346.28	A, F, M, R
18	346.58	Co	346.58	A, F, M, R
19	347.32	Ni	347.25	A, F, M, R
		Co	347.40	A, F, M, R
20	348.44	Ni	348.38, 348.59	A, F, M, R
		Co	348.34	A, F, M, R
21	349.31	Ni	349.30	A, F, M, R
22	350.30	Co	350.23	A, F, M, R
		Ni	350.09	A, F, M, R
23	350.67	Co	350.63	A, F, M, R
24	351.05	Ni	351.03	A, F, M, R
		Co	350.98, 351.04, 351.26	A, F, M, R
25	351.54	Ni	351.51	A, F, M, R
		Co	351.26, 351.35	A, F, M, R
26	352.04	Ni	351.98	A, F, M, R
27	352.53	Ni	352.45	A, F, M, R
		Co	352.68, 352.34	A, M, R

Table C-4. Spectral Lines of DTFT Exhaust Plume Doped with 50 ppm Waspaloy X (continued).

Peak No.	Wavelength (in nm)	Emitter	Contributing Lines (Wavelength in nm)	References
28	354.89	Ni	354.82	A, F, M, R
29	355.13	Co	355.06	A, F, M
30	356.62	Ni	356.64	A, F, M, R
		Co	356.50	A, F, M
31	357.24	Ni	357.19	A, F, M, R
32	357.61	Co	357.54, 357.50	A, F, M, R
33	357.86	Cr	357.87	A, F, M, R
34	358.72	Co	358.72, 358.52	A, F, M, R
		Ni	358.79	A, M, R
35	359.34	Cr	359.35	A, F, M, R
		Co	359.49	A, F, M, R
36	359.84	Ni	359.77	A, F, M, R
37	360.58	Cr	360.53	A, F, M, R
38	361.07	Ni	361.05, 361.27	A, F, M, R
39	361.94	Ni	361.94	A, F, M, R
40	367.01	Ni	367.04	A, M, R
41	367.50	Ni	367.41	A, M, R
42	371.94	Fe	371.99, 372.26	A, F, M, R
43	373.67	Fe	373.71, 373.49, 373.33	A, F, M, R
44	374.53	Fe	374.56, 374.59	A, F, M, R
45	374.90	Fe	374.95, 374.83	A, F, M, R
46	377.61	Ni	377.56	A, F, M, R
47	378.36	Ni	378.35	A, F, M, R
48	380.70	Ni	380.71	A, F, M, R
49	384.51	Co	384.55, 384.20	A, F, M, R
50	385.87	Fe	385.99, 385.64	A, F, M, R
		Ni	385.83	A, F, M, R
51	387.34	Co	387.31, 387.40	A, F, M, R
52	389.44	Co	389.41, 389.50	A, F, M, R
53	399.52	Co	399.53, 399.79	A, F, M, R
54	403.20	Mn	403.08, 403.31, 403.45	A, F, M, R
55	412.05	Co	412.13, 411.88	A, F, M, R
56	425.43	Cr	425.43	A, F, M, R

Table C-5. Spectral Lines of DTFT Exhaust Plume Doped with 50 ppm AISI 440C.

Peak No.	Wavelength (in nm)	Emitter	Contributing Lines (Wavelength in nm)	References
1	344.12	Fe	344.06, 344.10, 344.39	A, F, M, R
2	346.23	Ni	346.17	A, F, M, R
3	346.61	Fe	346.59	A, F, M, R
4	347.60	Fe	347.55, 347.67, 347.65	A, R
5	349.09	Fe	349.06	A, F, M, R
6	349.83	Fe	349.78	A, F, M, R
7	352.69	Fe	352.60, 352.62	A, F, M, R
		Ni	352.45	A, F, M, R
8	356.65	Fe	356.54	A, F, M, R
9	357.02	Fe	357.01, 357.03	M, R
10	357.89	Cr	357.87	A, F, M, R
11	358.14	Fe	358.12	A, F, M, R
12	358.76	Fe	358.70, 358.61	M, R
13	359.38	Cr	359.35	A, F, M, R
14	360.62	Cr	360.53	A, F, M, R
15	360.86	Fe	360.89, 361.02	M, R
16	361.98	Fe	361.88	A, F, M, R
		Ni	361.94	A, F, M, R
17	363.21	Fe	363.15	A, F, M, R
18	364.82	Fe	364.78, 364.95	M, R
19	368.04	Fe	367.99, 368.22	M, R
20	368.78	Fe	368.75, 368.60	M, R
21	370.63	Fe	370.56, 370.79, 370.78	M, R
22	371.99	Fe	371.99, 372.26	A, F, M, R
23	372.73	Fe	372.76	A, F, M, R
24	373.48	Fe	373.49, 373.33	A, F, M, R
25	373.72	Fe	373.71	A, F, M, R
26	374.59	Fe	374.56, 374.59	A, F, M, R
27	374.96	Fe	374.95, 374.83	A, F, M, R
28	375.82	Fe	375.82, 376.00	M, R
29	376.44	Fe	376.38, 376.55	F, M, R
30	376.68	Fe	376.72, 376.55	F, M, R
31	378.91	Fe	379.01, 378.79	M, R
32	379.65	Fe	379.50, 379.75	M, R

Table C-5. Spectral Lines of DTFT Exhaust Plume Doped with 50 ppm AISI 440C (continued).

Peak No.	Wavelength (in nm)	Emitter	Contributing Lines (Wavelength in nm)	References
33	380.02	Fe	379.95, 379.85	A, M, R
34	381.62	Fe	381.58	A, F, M, R
35	382.11	Fe	382.04, 382.12	M, R
36	382.48	Fe	382.44, 382.59, 382.78	A, F, M, R
37	383.47	Fe	383.42	A, F, M, R
38	384.09	Fe	384.10, 384.04, 383.93	M, R
39	385.07	Fe	385.00, 385.08	A, F, M
40	385.69	Fe	385.64	A, F, M, R
41	386.06	Fe	385.99	A, F, M, R
42	387.29	Fe	387.25, 387.38	M, R
43	387.91	Fe	387.86, 387.80	A, F, M, R
44	388.65	Fe	388.63, 388.70	M, R
45	389.63	Fe	389.57	A, F, M, R
46	390.00	Fe	389.97, 390.29	A, F, M, R
47	390.74	Fe	390.65	A, F, M, R
48	392.35	Fe	392.29, 392.03	A, F, M, R
49	392.84	Fe	392.79	A, F, M, R
50	393.08	Fe	393.03	A, F, M, R
51	403.30	Mn	403.08, 403.31, 403.45	A, F, M, R
52	404.65	Fe K	404.58 404.41, 404.72	A, F, M, R A, M, R
53	406.38	Fe	406.36	A, F, M, R
54	407.24	Fe	407.17	A, F, M, R
55	420.27	Fe	420.20, 420.40	M, R
56	425.56	Cr	425.43	A, F, M, R

Table C-6. Spectral Lines of DTFT Exhaust Plume Doped with 50 ppm NARloy-A.

Peak No.	Wavelength (in nm)	Emitter	Contributing Lines (Wavelength in nm)	References
1	324.78	Cu	324.75	A, F, M, R
2	327.40	Cu	327.40	A, F, M, R
3	328.03	Ag	328.07	A, F, M, R
4	338.25	Ag	338.29	A, F, M, R
5	404.43	K	404.41	A, F, M, R
6	404.68	K	404.72	A, F, M, R

Table C-7. Spectral Lines of DTFT Exhaust Plume Doped with 50 ppm NiCrAlY.

Peak No.	Wavelength (in nm)	Emitter	Contributing Lines (Wavelength in nm)	References
1	331.55	Ni	331.57	A, F, M, R
2	332.30	Ni	332.23, 332.03	A, M, R
3	336.28	Ni	336.16	A, F, M, R
4	336.66	Ni	336.62, 336.58	A, F, M, R
5	337.03	Ni	336.96, 337.20	A, M, R
6	337.53	Ni	337.42, 337.46	M, R
7	338.15	Ni	338.06, 338.09	A, F, M, R
8	339.39	Ni	339.30, 339.11	A, F, M, R
9	341.01	Ni	340.96	A, M, R
10	341.51	Ni	341.48, 341.39, 341.35	A, M, R
11	342.50	Ni	342.37	A, F, M, R
12	343.50	Ni	343.36	A, F, M, R
13	343.75	Ni	343.73	A, F, M, R
14	344.74	Ni	344.63	A, F, M, R
15	345.36	Ni	345.29	A, F, M, R
16	345.98	Ni	345.85	A, F, M, R
17	346.23	Ni	346.17	A, F, M, R
18	346.98	Ni	346.95, 346.75	A, M, R
19	347.35	Ni	347.25	A, F, M, R
20	348.47	Ni	348.38, 348.59	A, F, M, R
21	349.34	Ni	349.30	A, F, M, R
22	350.20	Ni	350.09	A, F, M, R
23	351.07	Ni	351.03	A, F, M, R
24	351.57	Ni	351.51	A, F, M, R
25	352.07	Ni	351.98	A, F, M, R
26	352.56	Ni	352.45	A, F, M, R
27	354.92	Ni	354.82	A, F, M, R
28	356.78	Ni	356.64	A, F, M, R
29	357.27	Ni	357.19	A, F, M, R
30	357.89	Cr	357.87	A, F, M, R
31	358.88	Ni	358.79	A, M, R
32	359.38	Cr	359.35	A, F, M, R
33	359.87	Ni	359.77	A, F, M, R

Table C-7. Spectral Lines of DTFT Exhaust Plume Doped with 50 ppm NiCrAlY (continued).

Peak No.	Wavelength (in nm)	Emitter	Contributing Lines (Wavelength in nm)	References
34	360.62	Cr	360.53	A, F, M, R
35	361.11	Ni	361.05, 361.27	A, F, M, R
36	361.98	Ni	361.94	A, F, M, R
37	366.43	Ni	366.41	A, M, R
38	367.17	Ni	367.04	A, M, R
39	367.42	Ni	367.41	A, M, R
40	372.24	Ni	372.25	A, M, R
41	373.85	Ni	373.68	A, M, R
42	377.67	Ni	377.56	A, F, M, R
43	378.41	Ni	378.35	A, F, M, R
44	379.40	Ni	379.36	A, M
45	380.76	Ni	380.71	A, F, M, R
46	383.22	Ni	383.17	A, M, R
47	385.94	Ni	385.83	A, F, M, R
48	396.16	Al	396.15	A, F, M, R
49	397.39	Ni	397.36	A, M, R
50	425.56	Cr	425.43	A, F, M, R

Table C-8. Spectral Lines of DTFT Exhaust Plume Doped with 50 ppm 347 CRES.

Peak No.	Wavelength (in nm)	Emitter	Contributing Lines (Wavelength in nm)	References
1	337.01	Ni	336.96, 337.20	A, M, R
2	338.13	Ni	338.06, 338.09	A, F, M, R
3	339.37	Ni	339.30, 339.11	A, F, M, R
4	341.49	Ni	341.48, 341.39, 341.35	A, M, R
5	342.36	Ni	342.37	A, F, M, R
6	343.35	Ni	343.36	A, F, M, R
7	343.72	Ni	343.73	A, F, M, R
8	344.10	Fe	344.06, 344.10	A, F, M, R
9	344.59	Ni	344.63	A, F, M, R
		Fe	344.39	A, F, M, R
10	345.34	Ni	345.29	A, F, M, R
11	345.96	Ni	345.85	A, F, M, R
12	346.21	Ni	346.17	A, F, M, R
13	346.58	Fe	346.59	A, F, M, R
14	347.32	Ni	347.25	A, F, M, R
15	347.57	Fe	347.55, 347.67, 347.65	A, R
16	348.44	Ni	348.38, 348.59	A, F, M, R
17	349.06	Fe	349.06	A, F, M, R
18	349.31	Ni	349.30	A, F, M, R
19	349.80	Fe	349.78	A, F, M, R
20	351.05	Ni	351.03	A, F, M, R
21	351.54	Ni	351.51	A, F, M, R
22	352.04	Ni	351.98	A, F, M, R
23	352.53	Ni	352.45	A, F, M, R
		Fe	352.60, 352.62	A, F, M, R
24	356.62	Ni	356.64	A, F, M, R
		Fe	356.54	A, F, M, R
25	357.11	Fe	357.01, 357.03	M, R
		Ni	357.19	A, F, M, R
26	357.86	Cr	357.87	A, F, M, R
27	358.11	Fe	358.12	A, F, M, R
28	358.72	Fe	358.70, 358.61	M, R
		Ni	358.79	A, M, R
29	359.34	Cr	359.35	A, F, M, R
30	360.58	Cr	360.53	A, F, M, R

Table C-8. Spectral Lines of DTFT Exhaust Plume Doped with 50 ppm 347 CRES (continued).

Peak No.	Wavelength (in nm)	Emitter	Contributing Lines (Wavelength in nm)	References
31	360.95	Fe	360.89, 361.02	M, R
		Ni	361.05, 361.27	A, F, M, R
32	361.94	Ni	361.94	A, F, M, R
		Fe	361.88	A, F, M, R
33	363.18	Fe	363.15	A, F, M, R
34	364.78	Fe	364.78, 364.95	M, R
35	367.99	Fe	367.99, 368.22	M, R
36	368.73	Fe	368.75, 368.60	M, R
37	370.59	Fe	370.56, 370.79, 370.78	M, R
38	371.94	Fe	371.99, 372.26	A, F, M, R
39	373.67	Fe	373.71, 373.49, 373.33	A, F, M, R
		Ni	373.68	A, M, R
40	374.53	Fe	374.56, 374.59	A, F, M, R
41	374.90	Fe	374.95, 374.83	A, F, M, R
42	375.77	Fe	375.82, 376.00	M, R
43	376.38	Fe	376.38, 376.55	F, M, R
44	376.75	Fe	376.72	A, F, M, R
45	379.83	Fe	379.95, 379.85, 379.75	M, R
46	381.56	Fe	381.58	A, F, M, R
47	382.05	Fe	382.04, 382.12	M, R
48	382.42	Fe	382.44, 382.59, 382.78	A, F, M, R
49	383.40	Fe	383.42	A, F, M, R
50	384.02	Fe	384.10, 384.04, 383.93	M, R
51	385.01	Fe	385.00, 385.08	A, F, M
52	385.62	Fe	385.64	A, F, M, R
53	385.99	Fe	385.99	A, F, M, R
54	387.22	Fe	387.25, 387.38	M, R
55	387.84	Fe	387.86, 387.80	A, F, M, R
56	388.57	Fe	388.63, 388.70	M, R
57	389.56	Fe	389.57	A, F, M, R
58	389.93	Fe	389.97, 390.29	A, F, M, R
59	390.67	Fe	390.65	A, F, M, R
60	392.27	Fe	392.29, 392.03	A, F, M, R
61	392.76	Fe	392.79	A, F, M, R
62	393.00	Fe	393.03	A, F, M, R

Table C-8. Spectral Lines of DTFT Exhaust Plume Doped with 50 ppm 347 CRES (continued).

Peak No.	Wavelength (in nm)	Emitter	Contributing Lines (Wavelength in nm)	References
63	403.33	Mn	403.08, 403.31, 403.45	A, F, M, R
64	404.55	Fe	404.58	A, F, M, R
		K	404.41, 404.72	A, F, M, R
65	406.27	Fe	406.36	A, F, M, R
66	407.14	Fe	407.17	A, F, M, R
67	425.43	Cr	425.43	A, F, M, R

Table C-9. Spectral Lines of DTFT Exhaust Plume Doped with 50 ppm A-286 CRES.

Peak No.	Wavelength (in nm)	Emitter	Contributing Lines (Wavelength in nm)	References
1	337.01	Ni	336.96, 337.20	A, M, R
2	338.13	Ni	338.06, 338.09	A, F, M, R
3	339.37	Ni	339.30, 339.11	A, F, M, R
4	341.49	Ni	341.48, 341.39, 341.35	A, M, R
5	342.48	Ni	342.37	A, F, M, R
6	343.47	Ni	343.36	A, F, M, R
7	343.85	Ni	343.73	A, F, M, R
8	344.10	Fe	344.06, 344.10	A, F, M, R
9	344.72	Ni	344.63	A, F, M, R
10	345.34	Ni	345.29	A, F, M, R
11	345.96	Ni	345.85	A, F, M, R
12	346.21	Ni	346.17	A, F, M, R
13	346.58	Fe	346.59	A, F, M, R
14	347.32	Ni	347.25	A, F, M, R
15	347.70	Fe	347.55, 347.67, 347.65	A, R
16	348.44	Ni	348.38, 348.59	A, F, M, R
17	349.06	Fe	349.06	A, F, M, R
18	349.31	Ni	349.30	A, F, M, R
19	349.80	Fe	349.78	A, F, M, R
20	350.18	Ni	350.09	A, F, M, R
21	351.05	Ni	351.03	A, F, M, R
22	351.54	Ni	351.51	A, F, M, R
23	352.04	Ni	351.98	A, F, M, R
24	352.53	Ni	352.45	A, F, M, R
		Fe	352.60, 352.62	A, F, M, R
25	356.62	Ni	356.64	A, F, M, R
		Fe	356.54	A, F, M, R
26	357.11	Fe	357.01, 357.03	M, R
		Ni	357.19	A, F, M, R
27	357.86	Cr	357.87	A, F, M, R
28	358.11	Fe	358.12	A, F, M, R
29	358.85	Ni	358.79	A, M, R
30	359.34	Cr	359.35	A, F, M, R
31	359.84	Ni	359.77	A, F, M, R
32	360.58	Cr	360.53	A, F, M, R

Table C-9. Spectral Lines of DTFT Exhaust Plume Doped with 50 ppm A-286 CRES (continued).

Peak No.	Wavelength (in nm)	Emitter	Contributing Lines (Wavelength in nm)	References
33	361.07	Ni	361.05, 361.27	A, F, M, R
		Fe	360.89, 361.02	M, R
34	361.94	Ni	361.94	A, F, M, R
		Fe	361.88	A, F, M, R
35	363.18	Fe	363.15	A, F, M, R
36	364.78	Fe	364.78, 364.95	M, R
37	367.99	Fe	367.99, 368.22	M, R
38	368.73	Fe	368.75, 368.60	M, R
39	370.59	Fe	370.56, 370.79, 370.78	M, R
40	372.07	Fe	371.99, 372.26	A, F, M, R
41	373.67	Fe	373.71, 373.49, 373.33	A, F, M, R
42	374.53	Fe	374.56, 374.59	A, F, M, R
43	374.90	Fe	374.95, 374.83	A, F, M, R
44	375.89	Fe	375.82, 376.00	M, R
45	376.38	Fe	376.38, 376.55	F, M, R
46	376.75	Fe	376.72	A, F, M, R
47	377.61	Ni	377.56	A, F, M, R
48	379.96	Fe	379.95, 379.85	A, M, R
49	380.70	Ni	380.71	A, F, M, R
50	382.05	Fe	382.04, 382.12	M, R
51	382.42	Fe	382.44, 382.59, 382.78	A, F, M, R
52	383.40	Fe	383.42	A, F, M, R
53	384.02	Fe	384.10, 384.04, 383.93	M, R
54	385.62	Fe	385.64	A, F, M, R
55	385.99	Fe	385.99	A, F, M, R
		Ni	385.83	A, F, M, R
56	387.84	Fe	387.86, 387.80	A, F, M, R
57	388.57	Fe	388.63, 388.70	M, R
58	389.56	Fe	389.57	A, F, M, R
59	389.93	Fe	389.97, 390.29	A, F, M, R
60	390.67	Fe	390.65	A, F, M, R
61	392.27	Fe	392.29, 392.03	A, F, M, R
62	392.76	Fe	392.79	A, F, M, R
63	393.00	Fe	393.03	A, F, M, R

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Table C-9. Spectral Lines of DTFT Exhaust Plume Doped with 50 ppm A-286 CRES (continued).

Peak No.	Wavelength (in nm)	Emitter	Contributing Lines (Wavelength in nm)	References
64	404.55	Fe	404.58	A, F, M, R
		K	404.41, 404.72	A, F, M, R
65	406.27	Fe	406.36	A, F, M, R
66	425.43	Cr	425.43	A, F, M, R

Table C-10. Spectral Lines of DTFT Exhaust Plume Doped with 50 ppm Inconel 625.

Peak No.	Wavelength (in nm)	Emitter	Contributing Lines (Wavelength in nm)	References
1	331.52	Ni	331.57	A, F, M, R
2	332.02	Ni	332.03, 332.23	A, M, R
3	336.14	Ni	336.16	A, F, M, R
4	336.63	Ni	336.62, 336.58	A, F, M, R
5	337.01	Ni	336.96, 337.20	A, M, R
6	338.13	Ni	338.06, 338.09	A, F, M, R
7	339.37	Ni	339.30, 339.11	A, F, M, R
8	341.49	Ni	341.48, 341.39, 341.35	A, M, R
9	342.36	Ni	342.37	A, F, M, R
10	343.35	Ni	343.36	A, F, M, R
11	343.72	Ni	343.73	A, F, M, R
12	344.10	Fe	344.06, 344.10	A, F, M, R
13	344.72	Ni	344.63	A, F, M, R
14	345.34	Ni	345.29	A, F, M, R
		Co	345.35, 345.52	A, F, M, R
15	345.96	Ni	345.85	A, F, M, R
16	346.21	Ni	346.17	A, F, M, R
17	347.32	Ni	347.25	A, F, M, R
		Co	347.40	A, F, M, R
18	348.44	Ni	348.38, 348.59	A, F, M, R
		Co	348.34	A, F, M, R
19	349.31	Ni	349.30	A, F, M, R
20	350.18	Ni	350.09	A, F, M, R
		Co	350.23	A, F, M, R
21	351.05	Ni	351.03	A, F, M, R
		Co	350.98, 351.04, 351.26	A, F, M, R
22	351.54	Ni	351.51	A, F, M, R
23	352.04	Ni	351.98	A, F, M, R
		Co	352.16, 352.01	A, F, M, R
24	352.53	Ni	352.45	A, F, M, R
		Fe	352.60, 352.62	A, F, M, R
		Co	352.68	A, F, M, R
25	354.89	Ni	354.82	A, F, M, R
26	356.62	Ni	356.64	A, F, M, R
27	357.24	Ni	357.19	A, F, M, R
28	357.86	Cr	357.87	A, F, M, R
29	358.85	Ni	358.79	A, M, R

Table C-10. Spectral Lines of DTFT Exhaust Plume Doped with 50 ppm Inconel 625 (continued).

Peak No.	Wavelength (in nm)	Emitter	Contributing Lines (Wavelength in nm)	References
30	359.34	Cr	359.35	A, F, M, R
31	359.84	Ni	359.77	A, F, M, R
32	360.58	Cr	360.53	A, F, M, R
33	361.07	Ni	361.05, 361.27	A, F, M, R
34	361.94	Ni	361.94	A, F, M, R
35	370.59	Fe	370.56, 370.79, 370.78	M, R
36	371.94	Fe	371.99, 372.26	A, F, M, R
		Ni	372.25	A, M, R
37	373.67	Fe	373.71, 373.49, 373.33	A, F, M, R
		Ni	373.68	A, M, R
38	374.53	Fe	374.56, 374.59	A, F, M, R
39	374.90	Fe	374.95, 374.83	A, F, M, R
40	377.49	Ni	377.56	A, F, M, R
41	378.36	Ni	378.35	A, F, M, R
42	380.70	Ni	380.71	A, F, M, R
43	382.05	Fe	382.04, 382.12	M, R
44	382.42	Fe	382.44, 382.59, 382.78	A, F, M, R
45	385.99	Fe	385.99, 385.64	A, F, M, R
46	387.84	Fe	387.86, 387.80	A, F, M, R
		Ni	385.83	A, F, M, R
47	388.57	Fe	388.63, 388.70	M, R
48	389.93	Fe	389.97, 390.29	A, F, M, R
49	392.27	Fe	392.29, 392.03	A, F, M, R
50	393.00	Fe	393.03, 392.79	A, F, M, R
51	403.20	Mn	403.08, 403.31, 403.45	A, F, M, R
52	425.43	Cr	425.43	A, F, M, R

Table C-11. Spectral Lines of DTFT Exhaust Plume Doped with 50 ppm Inconel 600.

Peak No.	Wavelength (in nm)	Emitter	Contributing Lines (Wavelength in nm)	References
1	331.52	Ni	331.57	A, F, M, R
2	332.02	Ni	332.03	A, M, R
3	332.27	Ni	332.23	A, M, R
4	336.14	Ni	336.16	A, F, M, R
5	336.63	Ni	336.62, 336.58	A, F, M, R
6	337.01	Ni	336.96, 337.20	A, M, R
7	338.00	Ni	338.06, 338.09	A, F, M, R
8	339.25	Ni	339.30, 339.11	A, F, M, R
9	341.49	Ni	341.48, 341.39, 341.35	A, M, R
10	342.36	Ni	342.37	A, F, M, R
11	343.35	Ni	343.36	A, F, M, R
12	343.72	Ni	343.73	A, F, M, R
13	344.10	Fe	344.06, 344.10	A, F, M, R
14	344.59	Ni	344.63	A, F, M, R
15	345.34	Ni	345.29	A, F, M, R
16	345.83	Ni	345.85	A, F, M, R
17	346.21	Ni	346.17	A, F, M, R
18	347.20	Ni	347.25	A, F, M, R
19	348.44	Ni	348.38, 348.59	A, F, M, R
20	349.31	Ni	349.30	A, F, M, R
21	350.05	Ni	350.09	A, F, M, R
22	351.05	Ni	351.03	A, F, M, R
23	351.54	Ni	351.51	A, F, M, R
24	351.91	Ni	351.98	A, F, M, R
25	352.41	Ni	352.45	A, F, M, R
26	354.76	Ni	354.82	A, F, M, R
27	356.62	Ni	356.64	A, F, M, R
28	357.24	Ni	357.19	A, F, M, R
29	357.86	Cr	357.87	A, F, M, R
30	359.34	Cr	359.35	A, F, M, R
31	359.71	Ni	359.77	A, F, M, R
32	360.58	Cr	360.53	A, F, M, R
33	361.07	Ni	361.05, 361.27	A, F, M, R

Table C-11. Spectral Lines of DTFT Exhaust Plume Doped with 50 ppm Inconel 600 (continued).

Peak No.	Wavelength (in nm)	Emitter	Contributing Lines (Wavelength in nm)	References
34	361.94	Ni	361.94	A, F, M, R
35	371.94	Fe	371.99, 372.26	A, F, M, R
		Ni	372.25	A, M, R
36	373.67	Fe	373.71, 373.49, 373.33	A, F, M, R
		Ni	373.68	A, M, R
37	374.53	Fe	374.56, 374.59	A, F, M, R
38	374.78	Fe	374.95, 374.83	A, F, M, R
39	377.49	Ni	377.56	A, F, M, R
40	378.36	Ni	378.35	A, F, M, R
41	380.70	Ni	380.71	A, F, M, R
42	382.05	Fe	382.04, 382.12	M, R
43	382.42	Fe	382.44, 382.59, 382.78	A, F, M, R
44	385.87	Fe	385.99, 385.64	A, F, M, R
		Ni	385.83	A, F, M, R
45	387.71	Fe	387.86, 387.80	A, F, M, R
46	388.57	Fe	388.63, 388.70	A, F, M, R
47	393.00	Fe	393.03	A, F, M, R
48	402.96	Mn	403.08	A, F, M, R
49	403.20	Mn	403.31, 403.45	A, F, M, R
50	404.31	K	404.41	A, F, M, R
51	404.55	K	404.72	A, F, M, R
52	425.31	Cr	425.43	A, F, M, R

Table C-12. Spectral Lines of DTFT Exhaust Plume Doped with 50 ppm Incoloy 903.

Peak No.	Wavelength (in nm)	Emitter	Contributing Lines (Wavelength in nm)	References
1	331.52	Ni	331.57	A, F, M, R
2	336.14	Ni	336.16	A, F, M, R
3	336.63	Ni	336.62, 336.58	A, F, M, R
4	337.01	Ni	336.96, 337.20	A, M, R
5	338.13	Ni	338.06, 338.09	A, F, M, R
6	339.25	Ni	339.30, 339.11	A, F, M, R
7	340.49	Co	340.51	A, F, M, R
8	340.99	Co	340.92	A, F, M, R
9	341.49	Ni	341.48, 341.39, 341.35	A, M, R
		Co	341.23, 341.26, 341.72	A, F, M, R
10	342.36	Ni	342.37	A, F, M, R
11	343.35	Ni	343.36	A, F, M, R
		Co	343.30, 343.16	A, F, M, R
12	343.72	Ni	343.73	A, F, M, R
13	344.10	Fe	344.06, 344.10	A, F, M, R
14	344.59	Ni	344.63	A, F, M, R
15	344.96	Co	344.92, 344.94	A, F, M, R
16	345.34	Co	345.35, 345.52	A, F, M, R
		Ni	345.29	A, F, M, R
17	345.83	Ni	345.85	A, F, M, R
18	346.21	Ni	346.17	A, F, M, R
		Co	346.28	A, F, M, R
19	346.58	Co	346.58	A, F, M, R
		Fe	346.59	A, F, M, R
20	347.32	Co	347.40	A, F, M, R
		Ni	347.25	A, F, M, R
		Fe	347.55, 347.67, 347.65	A, R
21	348.44	Ni	348.38, 348.59	A, F, M, R
		Co	348.34	A, F, M, R
22	349.31	Ni	349.30	A, F, M, R
		Fe	349.06	A, F, M, R
		Co	349.57	A, F, M, R
23	349.80	Fe	349.78	A, F, M, R
24	350.18	Co	350.23	A, F, M, R
		Ni	350.09	A, F, M, R
25	350.55	Co	350.63	A, F, M, R
26	351.05	Ni	351.03	A, F, M, R
		Co	350.98, 351.04	A, F, M, R
27	351.54	Ni	351.51	A, F, M, R
		Co	351.26, 351.35	A, F, M, R

Table C-12. Spectral Lines of DTFT Exhaust Plume Doped with 50 ppm Incoloy 903 (continued).

Peak No.	Wavelength (in nm)	Emitter	Contributing Lines (Wavelength in nm)	References
28	352.04	Ni	351.98	A, F, M, R
		Co	352.16, 352.01	A, F, M, R
29	352.41	Ni	352.45	A, F, M, R
		Co	352.98, 352.68, 352.34, 352.90	A, M, R
		Fe	352.60, 352.62	A, F, M, R
30	353.28	Co	353.34	A, F, M, R
31	354.89	Ni	354.82	A, F, M, R
32	356.62	Ni	356.64	A, F, M, R
		Fe	356.54	A, F, M, R
33	357.11	Ni	357.19	A, F, M, R
		Fe	357.01, 357.03	M, R
		Co	356.94	A, F, M, R
34	357.49	Co	357.54, 357.50	A, F, M, R
35	358.11	Fe	358.12	A, F, M, R
36	358.72	Co	358.72, 358.52	A, F, M, R
		Ni	358.79	A, M, R
37	359.71	Ni	359.77	A, F, M, R
		Co	359.49	A, F, M, R
38	361.07	Ni	361.05, 361.27	A, F, M, R
		Fe	360.89, 361.02	M, R
39	361.94	Ni	361.94	A, F, M, R
		Fe	361.88	A, F, M, R
40	363.18	Fe	363.15	A, F, M, R
41	364.78	Fe	364.78, 364.95	M, R
42	367.99	Fe	367.99, 368.22	M, R
43	370.59	Fe	370.56, 370.79, 370.78	M, R
44	371.94	Fe	371.99, 372.26	A, F, M, R
		Ni	372.25	A, M, R
45	373.42	Fe	373.49, 373.33	A, F, M, R
46	373.67	Fe	373.71	A, F, M, R
		Ni	373.68	A, M, R
47	374.53	Fe	374.56, 374.59	A, F, M, R
48	374.78	Fe	374.95, 374.83	A, F, M, R
49	375.77	Fe	375.82, 376.00	M, R
50	376.26	Fe	376.38	F, M, R
51	376.63	Fe	376.72, 376.55	A, F, M, R
52	377.49	Ni	377.56	A, F, M, R
53	377.74	Fe	377.65	M, R
54	378.48	Fe	378.59	M, R
		Ni	378.35	A, F, M, R

Table C-12. Spectral Lines of DTFT Exhaust Plume Doped with 50 ppm Incoloy 903 (continued).

Peak No.	Wavelength (in nm)	Emitter	Contributing Lines (Wavelength in nm)	References
55	380.70	Ni	380.71	A, F, M, R
56	382.05	Fe	382.04, 382.12	M, R
57	382.42	Fe	382.44, 382.59, 382.78	A, F, M, R
58	383.28	Fe	383.42	A, F, M, R
59	384.02	Fe	384.10, 384.04, 383.93	M, R
60	384.51	Co	384.55, 384.20	A, F, M, R
61	385.99	Fe	385.99, 385.64	A, F, M, R
		Ni	385.83	A, F, M, R
62	387.22	Co	387.31, 387.40	A, F, M, R
		Fe	387.25, 387.38	M, R
63	387.84	Fe	387.86, 387.80	A, F, M, R
64	388.57	Fe	388.63, 388.70	M, R
65	389.44	Co	389.41, 389.50	A, F, M, R
		Fe	389.57	A, F, M, R
66	389.93	Fe	389.97, 390.29	A, F, M, R
67	391.90	Fe	392.03	A, F, M, R
68	392.27	Fe	392.29	A, F, M, R
69	393.00	Fe	393.03, 392.79	A, F, M, R
70	399.39	Co	399.53, 399.79	A, F, M, R
71	404.43	Fe	404.58	A, F, M, R
		K	404.41, 404.72	A, F, M, R
72	412.05	Co	412.13, 411.88	A, F, M, R

Table C-13. Spectral Lines of DTFT Exhaust Plume Doped with 50 ppm Inconel X-750.

Peak No.	Wavelength (in nm)	Emitter	Contributing Lines (Wavelength in nm)	References
1	331.65	Ni	331.57	A, F, M, R
2	332.02	Ni	332.03, 332.23	A, M, R
3	336.14	Ni	336.16	A, F, M, R
4	336.63	Ni	336.62, 336.58	A, F, M, R
5	337.01	Ni	336.96, 337.20	A, M, R
6	338.13	Ni	338.06, 338.09	A, F, M, R
7	339.37	Ni	339.30, 339.11	A, F, M, R
8	341.49	Ni	341.48, 341.39, 341.35	A, M, R
9	342.36	Ni	342.37	A, F, M, R
10	343.35	Ni	343.36	A, F, M, R
11	343.72	Ni	343.73	A, F, M, R
12	344.10	Fe	344.06, 344.10	A, F, M, R
13	344.72	Ni	344.63	A, F, M, R
14	345.34	Ni	345.29	A, F, M, R
15	345.83	Ni	345.85	A, F, M, R
16	346.21	Ni	346.17	A, F, M, R
17	347.32	Ni	347.25	A, F, M, R
18	348.44	Ni	348.38, 348.59	A, F, M, R
19	349.31	Ni	349.30	A, F, M, R
20	350.18	Ni	350.09	A, F, M, R
21	351.05	Ni	351.03	A, F, M, R
22	351.54	Ni	351.51	A, F, M, R
23	352.04	Ni	351.98	A, F, M, R
24	352.53	Ni	352.45	A, F, M, R
25	354.89	Ni	345.82	A, F, M, R
26	356.62	Ni	356.64	A, F, M, R
27	357.24	Ni	357.19	A, F, M, R
28	357.86	Cr	357.87	A, F, M, R
29	359.34	Cr	359.35	A, F, M, R
30	359.84	Ni	359.77	A, F, M, R
31	360.58	Cr	360.53	A, F, M, R
32	361.07	Ni	361.05, 361.27	A, F, M, R
33	361.94	Ni	361.94	A, F, M, R

Table C-13. Spectral Lines of DTFT Exhaust Plume Doped with 50 ppm Inconel X-750 (continued).

Peak No.	Wavelength (in nm)	Emitter	Contributing Lines (Wavelength in nm)	References
34	371.94	Fe	371.99, 372.26	A, F, M, R
		Ni	372.25	A, M, R
35	373.67	Fe	373.71, 373.49, 373.33	A, F, M, R
		Ni	373.68	A, M, R
36	374.53	Fe	374.56, 374.59	A, F, M, R
37	374.90	Fe	374.95, 374.83	A, F, M, R
38	377.49	Ni	377.56	A, F, M, R
39	378.36	Ni	378.35	A, F, M, R
40	380.70	Ni	380.71	A, F, M, R
41	382.54	Fe	382.44, 382.59, 382.78	A, F, M, R
42	385.87	Fe	385.99, 385.64	A, F, M, R
		Ni	385.83	A, F, M, R
43	388.57	Fe	388.63, 388.70	M, R
44	403.33	Mn	403.08, 403.31, 403.45	A, F, M, R
45	425.43	Cr	425.43	A, F, M, R

Table C-14. Spectral Lines of DTFT Exhaust Plume Doped with 50 ppm Armco 21-6-9.

Peak No.	Wavelength (in nm)	Emitter	Contributing Lines (Wavelength in nm)	References
1	337.01	Ni	336.96, 337.20	A, M, R
2	338.13	Ni	338.06, 338.09	A, F, M, R
3	339.37	Ni	339.30, 339.11	A, F, M, R
4	341.49	Ni	341.48, 341.39, 341.35	A, M, R
5	343.35	Ni	343.36	A, F, M, R
6	344.10	Fe	344.06, 344.10	A, F, M, R
7	344.72	Ni	344.63	A, F, M, R
8	345.96	Ni	345.85	A, F, M, R
9	346.21	Ni	346.17	A, F, M, R
10	346.58	Fe	346.59	A, F, M, R
11	347.32	Ni	347.25	A, F, M, R
12	347.70	Fe	347.55, 347.67, 347.65	A, R
13	348.44	Ni	348.38, 348.59	A, F, M, R
14	349.06	Fe	349.06	A, F, M, R
15	349.31	Ni	349.30	A, F, M, R
16	349.80	Fe	349.78	A, F, M, R
17	351.05	Ni	351.03	A, F, M, R
18	351.54	Ni	351.51	A, F, M, R
19	352.53	Ni	352.45	A, F, M, R
		Fe	352.60, 352.62	A, F, M, R
20	356.62	Fe	356.54	A, F, M, R
		Ni	356.64	A, F, M, R
21	357.11	Fe	357.01, 357.03	M, R
		Ni	357.19	A, F, M, R
22	357.86	Cr	357.87	A, F, M, R
23	358.11	Fe	358.12	A, F, M, R
24	358.72	Fe	358.70, 358.61	M, R
25	359.34	Cr	359.35	A, F, M, R
26	360.58	Cr	360.53	A, F, M, R
27	361.07	Fe	360.89, 361.02	M, R,
		Ni	361.05, 361.27	A, F, M, R
28	361.94	Ni	361.94	A, F, M, R
		Fe	361.88	A, F, M, R
29	363.18	Fe	363.15	A, F, M, R
30	364.78	Fe	364.78, 364.95	M, R
31	367.99	Fe	367.99, 368.22	M, R

Table C-14. Spectral Lines of DTFT Exhaust Plume Doped with 50 ppm Armco 21-6-9 (continued).

Peak No.	Wavelength (in nm)	Emitter	Contributing Lines (Wavelength in nm)	References
32	370.59	Fe	370.56, 370.79, 370.78	M, R
33	370.96	Fe	370.92	A, M, R
34	371.94	Fe	371.99, 372.26	A, F, M, R
35	373.67	Fe	373.71, 373.49, 373.33	A, F, M, R
		Ni	373.68	A, M, R
36	374.53	Fe	374.56, 374.59	A, F, M, R
37	374.90	Fe	374.95, 374.83	A, F, M, R
38	375.77	Fe	375.82, 376.00	M, R
39	376.38	Fe	376.38, 376.55	F, M, R
40	382.05	Fe	382.04, 382.12	M, R
41	382.42	Fe	382.44, 382.59, 382.78	A, F, M, R
42	383.40	Fe	383.42	A, F, M, R
43	384.02	Fe	384.10, 384.04, 383.93	M, R
44	385.62	Fe	385.64	A, F, M, R
45	385.99	Fe	385.99	A, F, M, R
46	387.84	Fe	387.86, 387.80	A, F, M, R
47	388.57	Fe	388.63, 388.70	M, R
48	389.56	Fe	389.57	A, F, M, R
49	389.93	Fe	389.97, 390.29	A, F, M, R
50	392.27	Fe	392.29, 392.03	A, F, M, R
51	392.76	Fe	392.79	A, F, M, R
52	393.00	Fe	393.03	A, F, M, R
53	403.33	Mn	403.08, 403.31, 403.45	A, F, M, R
54	404.55	Fe	404.58	A, F, M, R
		K	404.41	A, F, M, R
55	425.43	Cr	425.43	A, F, M, R

Table C-15. Spectral Lines of DTFT Exhaust Plume Doped with 50 ppm K-Monel.

Peak No.	Wavelength (in nm)	Emitter	Contributing Lines (Wavelength in nm)	References
1	324.78	Cu	324.75	A, F, M, R
2	327.40	Cu	327.40	A, F, M, R
3	331.52	Ni	331.57	A, F, M, R
4	332.02	Ni	332.03, 332.23	A, M, R
5	336.14	Ni	336.16	A, F, M, R
6	336.63	Ni	336.62, 336.58	A, F, M, R
7	337.01	Ni	336.96, 337.20	A, M, R
8	338.13	Ni	338.06, 338.09	A, F, M, R
9	339.25	Ni	339.30, 339.11	A, F, M, R
10	341.49	Ni	341.48, 341.39, 341.35	A, M, R
11	342.36	Ni	342.37	A, F, M, R
12	343.35	Ni	343.36	A, F, M, R
13	343.72	Ni	343.73	A, F, M, R
14	344.59	Ni	344.63	A, F, M, R
15	345.34	Ni	345.29	A, F, M, R
16	345.83	Ni	345.85	A, F, M, R
17	346.21	Ni	346.17	A, F, M, R
18	347.32	Ni	347.25	A, F, M, R
19	348.44	Ni	348.38, 348.59	A, F, M, R
20	349.31	Ni	349.30	A, F, M, R
21	350.18	Ni	350.09	A, F, M, R
22	351.05	Ni	351.03	A, F, M, R
23	351.54	Ni	351.51	A, F, M, R
24	352.04	Ni	351.98	A, F, M, R
25	352.41	Ni	352.45	A, F, M, R
26	354.76	Ni	354.82	A, F, M, R
27	356.62	Ni	356.64	A, F, M, R
28	357.24	Ni	357.19	A, F, M, R
29	359.71	Ni	359.77	A, F, M, R
30	361.07	Ni	361.05, 361.27	A, F, M, R
31	361.94	Ni	361.94	A, F, M, R
32	371.94	Fe	371.99, 372.26	A, F, M, R
33	372.31	Ni	372.25	A, M, R

Table C-15. Spectral Lines of DTFT Exhaust Plume Doped with 50 ppm K-Monel (continued).

Peak No.	Wavelength (in nm)	Emitter	Contributing Lines (Wavelength in nm)	References
34	377.49	Ni	377.56	A, F, M, R
35	378.36	Ni	378.35	A, F, M, R
36	380.70	Ni	380.71	A, F, M, R
37	385.74	Ni	385.83	A, F, M, R
		Fe	385.99, 385.64	A, F, M, R

Table C-16. Spectral Lines of DTFT Exhaust Plume Doped with 50 ppm Hastelloy B.

Peak No.	Wavelength (in nm)	Emitter	Contributing Lines (Wavelength in nm)	References
1	331.52	Ni	331.57	A, F, M, R
2	332.02	Ni	332.03, 332.23	A, M, R
3	336.14	Ni	336.16	A, F, M, R
4	336.63	Ni	336.62, 336.58	A, F, M, R
5	337.01	Ni	336.96, 337.20	A, M, R
6	338.00	Ni	338.06, 338.09	A, F, M, R
7	339.25	Ni	339.30, 339.11	A, F, M, R
8	340.61	Co	340.51	A, F, M, R
9	341.49	Ni	341.48, 341.39, 341.35	A, M, R
		Co	341.23, 341.26	A, F, M, R
10	342.36	Ni	342.37	A, F, M, R
11	343.35	Ni	343.36	A, F, M, R
		Co	343.30, 343.16	A, F, M, R
12	343.72	Ni	343.73	A, F, M, R
13	344.10	Fe	344.06, 344.10	A, F, M, R
14	344.59	Ni	344.63	A, F, M, R
		Co	344.36, 344.29	A, F, M, R
		Fe	344.39	A, F, M, R
15	345.34	Ni	345.29	A, F, M, R
		Co	345.35, 345.52	A, F, M, R
16	345.83	Ni	345.85	A, F, M, R
17	346.21	Ni	346.17	A, F, M, R
		Co	346.28	A, F, M, R
18	346.58	Co	346.58	A, F, M, R
		Fe	346.59	A, F, M, R
19	347.32	Ni	347.25	A, F, M, R
		Co	347.40	A, F, M, R
		Fe	347.55, 347.67, 347.65	A, R
20	348.44	Ni	348.38, 348.59	A, F, M, R
21	349.31	Ni	349.30	A, F, M, R
22	350.18	Co	350.23	A, F, M, R
		Ni	350.09	A, F, M, R
23	351.05	Ni	351.03	A, F, M, R
		Co	350.98, 351.04	A, F, M, R
24	351.54	Ni	351.51	A, F, M, R
		Co	351.26, 351.35	A, F, M, R
25	352.04	Ni	351.98	A, F, M, R
		Co	352.16, 352.01	A, F, M, R
26	352.41	Ni	352.45	A, F, M, R
		Co	352.34, 352.98, 352.68, 352.90	A, M, R

Table C-16. Spectral Lines of DTFT Exhaust Plume Doped with 50 ppm Hastelloy B (continued).

Peak No.	Wavelength (in nm)	Emitter	Contributing Lines (Wavelength in nm)	References
27	354.89	Ni	354.82	A, F, M, R
28	356.62	Ni	356.64	A, F, M, R
29	357.24	Ni	357.19	A, F, M, R
		Fe	357.01, 357.03	M, R
		Co	356.94	A, F, M, R
30	357.61	Co	357.54, 357.50	A, F, M, R
		Cr	357.87	A, F, M, R
31	358.11	Fe	358.12	A, F, M, R
32	359.71	Ni	359.77	A, F, M, R
33	361.07	Ni	361.05, 361.27	A, F, M, R
		Fe	360.89, 361.02	M, R
34	361.94	Ni	361.94	A, F, M, R
		Fe	361.88	A, F, M, R
35	371.94	Fe	371.99, 372.26	A, F, M, R
		Ni	372.25	A, M, R
36	373.67	Fe	373.71, 373.49, 373.33	A, F, M, R
		Ni	373.68	A, M, R
37	374.53	Fe	374.56, 374.59	A, F, M, R
		Co	374.55	A, F, M, R
38	374.90	Fe	374.95, 374.83	A, F, M, R
39	377.49	Ni	377.56	A, F, M, R
40	378.23	Ni	378.35	A, F, M, R
41	380.70	Ni	380.71	A, F, M, R
42	382.05	Fe	382.04, 382.12	M, R
43	382.42	Fe	382.44, 382.59	A, F, M, R
44	385.87	Ni	385.83	A, F, M, R
		Fe	385.99	A, F, M, R
45	387.22	Co	387.31, 387.40	A, F, M, R
46	388.57	Fe	388.63, 388.70	M, R
47	393.00	Fe	393.03	A, F, M, R
48	402.96	Mn	403.08	A, F, M, R
49	403.20	Mn	403.31, 403.45	A, F, M, R
50	404.31	K	404.41	A, F, M, R
51	404.68	K	404.72	A, F, M, R
52	425.31	Cr	425.43	A, F, M, R

Table C-17. Spectral Lines of DTFT Exhaust Plume Doped with 50 ppm Hastelloy B-2.

Peak No.	Wavelength (in nm)	Emitter	Contributing Lines (Wavelength in nm)	References
1	331.52	Ni	331.57	A, F, M, R
2	332.02	Ni	332.03, 332.23	A, M, R
3	336.14	Ni	336.16	A, F, M, R
4	336.63	Ni	336.62, 336.58	A, F, M, R
5	337.01	Ni	336.96, 337.20	A, M, R
6	338.13	Ni	338.06, 338.09	A, F, M, R
7	339.37	Ni	339.30, 339.11	A, F, M, R
8	340.61	Co	340.51	A, F, M, R
9	341.49	Ni	341.48, 341.39, 341.35	A, M, R
		Co	341.23, 341.26	A, F, M, R
10	342.36	Ni	342.37	A, F, M, R
11	343.35	Ni	343.36	A, F, M, R
		Co	343.30, 343.16	A, F, M, R
12	343.72	Ni	343.73	A, F, M, R
13	344.72	Ni	344.63	A, F, M, R
14	345.34	Ni	345.29	A, F, M, R
		Co	345.35, 345.52	A, F, M, R
15	345.83	Ni	345.85	A, F, M, R
16	346.21	Ni	346.17	A, F, M, R
		Co	346.28	A, F, M, R
17	347.32	Ni	347.25	A, F, M, R
		Co	347.40	A, F, M, R
18	348.44	Ni	348.38, 348.59	A, F, M, R
19	349.31	Ni	349.30	A, F, M, R
20	350.18	Co	350.23	A, F, M, R
		Ni	350.09	A, F, M, R
21	351.05	Ni	351.03	A, F, M, R
		Co	350.98, 351.04	A, F, M, R
22	351.54	Ni	351.51	A, F, M, R
		Co	351.26, 351.35	A, F, M, R
23	352.04	Ni	351.98	A, F, M, R
		Co	352.16, 352.01	A, F, M, R
24	352.53	Ni	352.45	A, F, M, R
		Co	352.34, 352.98, 352.68, 352.90	A, M, R
25	354.89	Ni	354.82	A, F, M, R
26	356.62	Ni	356.64	A, F, M, R
27	357.24	Ni	357.19	A, F, M, R
		Co	356.94	A, F, M, R

Table C-17. Spectral Lines of DTFT Exhaust Plume Doped with 50 ppm Hastelloy B-2 (continued).

Peak No.	Wavelength (in nm)	Emitter	Contributing Lines (Wavelength in nm)	References
28	359.84	Ni	359.77	A, F, M, R
29	361.07	Ni	361.05, 361.27	A, F, M, R
30	361.94	Ni	361.94	A, F, M, R
31	366.39	Ni	366.41	A, M, R
32	367.01	Ni	367.04	A, M, R
33	367.50	Ni	367.41	A, M, R
34	371.94	Fe	371.99, 372.26	A, F, M, R
		Ni	372.25	A, M, R
35	372.31	Ni	372.25	A, M, R
36	373.67	Fe	373.71, 373.49, 373.33	A, F, M, R
		Ni	373.68	A, M, R
37	374.53	Fe	374.54, 374.59	A, F, M, R
		Co	374.55	A, F, M, R
38	374.90	Fe	374.95, 374.83	A, F, M, R
39	377.49	Ni	377.56	A, F, M, R
40	378.36	Ni	378.35	A, F, M, R
41	380.70	Ni	380.71	A, F, M, R
42	385.87	Ni	385.83	A, F, M, R
		Fe	385.99	A, F, M, R
43	387.34	Co	387.31, 387.40	A, F, M, R
44	403.33	Mn	403.08, 403.31, 403.45	A, F, M, R
45	404.43	K	404.41, 404.72	A, F, M, R
46	425.43	Cr	425.43	A, F, M, R

Table C-18. Spectral Lines of DTFT Exhaust Plume Doped with 50 ppm Hastelloy X.

Peak No.	Wavelength (in nm)	Emitter	Contributing Lines (Wavelength in nm)	References
1	331.52	Ni	331.57	A, F, M, R
2	336.14	Ni	336.16	A, F, M, R
3	336.63	Ni	336.62, 336.58	A, F, M, R
4	337.01	Ni	336.96, 337.20	A, M, R
5	338.13	Ni	338.06, 338.09	A, F, M, R
6	339.37	Ni	339.30, 339.11	A, F, M, R
7	341.49	Ni	341.48, 341.39, 341.35	A, M, R
		Co	341.23, 341.26	A, F, M, R
8	342.36	Ni	342.37	A, F, M, R
9	343.35	Ni	343.36	A, F, M, R
		Co	343.30, 343.16	A, F, M, R
10	343.72	Ni	343.73	A, F, M, R
11	344.10	Fe	344.06, 344.10	A, F, M, R
12	344.72	Ni	344.63	A, F, M, R
		Co	344.92, 344.94	A, F, M, R
13	345.34	Ni	345.29	A, F, M, R
		Co	345.35, 345.52	A, F, M, R
14	345.96	Ni	345.85	A, F, M, R
15	346.21	Ni	346.17	A, F, M, R
16	346.70	Fe	346.59	A, F, M, R
		Co	346.58	A, F, M, R
17	347.32	Ni	347.25	A, F, M, R
		Fe	347.55, 347.67, 347.65	A, R
		Co	347.40	A, F, M, R
18	348.44	Ni	348.38, 348.59	A, F, M, R
19	349.31	Ni	349.30	A, F, M, R
		Fe	349.06, 349.78	A, F, M, R
20	350.18	Ni	350.09	A, F, M, R
		Co	350.23	A, F, M, R
21	351.05	Ni	351.03	A, F, M, R
		Co	350.98, 351.04, 351.26	A, F, M, R
22	351.54	Ni	351.51	A, F, M, R
23	352.04	Ni	351.98	A, F, M, R
24	352.53	Ni	352.45	A, F, M, R
		Fe	352.60, 352.62	A, F, M, R
25	354.89	Ni	354.82	A, F, M, R
26	356.62	Ni	356.64	A, F, M, R
		Fe	356.54	A, F, M, R

Table C-18. Spectral Lines of DTFT Exhaust Plume Doped with 50 ppm Hastelloy X (continued).

Peak No.	Wavelength (in nm)	Emitter	Contributing Lines (Wavelength in nm)	References
27	357.24	Ni	357.19	A, F, M, R
		Fe	357.01, 357.03	M, R
		Co	357.54, 357.50	A, F, M, R
28	357.86	Cr	357.87	A, F, M, R
		Fe	358.12	A, F, M, R
29	359.34	Cr	359.35	A, F, M, R
30	359.84	Ni	359.77	A, F, M, R
31	360.58	Cr	360.53	A, F, M, R
32	361.07	Ni	361.05, 361.27	A, F, M, R
		Fe	360.89, 361.02	A, F, M, R
33	361.94	Ni	361.94	A, F, M, R
		Fe	361.88	A, F, M, R
34	367.99	Fe	367.99, 368.72	M, R
35	370.59	Fe	370.56, 370.79, 370.78	M, R
36	371.94	Fe	371.99, 372.26	A, F, M, R
		Ni	372.25	A, M, R
37	373.67	Fe	373.71, 373.49, 373.33	A, F, M, R
		Ni	373.68	A, M, R
38	374.53	Fe	374.56, 374.59	A, F, M, R
39	374.90	Fe	374.95, 374.83	A, F, M, R
40	375.77	Fe	375.82, 376.00	M, R
41	377.61	Ni	377.56	A, F, M, R
42	378.36	Ni	378.35	A, F, M, R
43	380.70	Ni	380.71	A, F, M, R
44	382.05	Fe	382.04, 382.12	M, R
45	382.42	Fe	382.44, 382.59, 382.78	A, F, M, R
46	383.40	Fe	383.42	A, F, M, R
47	385.99	Fe	385.99, 385.64	A, F, M, R
		Ni	385.83	A, F, M, R
48	387.84	Fe	387.86, 387.80	A, F, M, R
		Co	387.31, 387.40	A, F, M, R
49	388.57	Fe	388.63, 388.70	M, R
50	389.56	Fe	389.57	A, F, M, R
51	389.93	Fe	389.97, 390.29	A, F, M, R
52	392.27	Fe	392.29, 392.03	A, F, M, R
53	392.76	Fe	392.79	A, F, M, R
54	393.00	Fe	393.03	A, F, M, R
55	403.33	Mn	403.08, 403.31, 403.45	A, F, M, R

Table C-18. Spectral Lines of DTFT Exhaust Plume Doped with 50 ppm Hastelloy X (continued).

Peak No.	Wavelength (in nm)	Emitter	Contributing Lines (Wavelength in nm)	References
56	404.43	K	404.41	A, F, M, R
57	404.68	Fe	404.58	A, F, M, R
		K	404.72	A, F, M, R
58	425.43	Cr	425.43	A, F, M, R

Table C-19. Spectral Lines of DTFT Exhaust Plume Doped with 50 ppm Rene 41.

Peak No.	Wavelength (in nm)	Emitter	Contributing Lines (Wavelength in nm)	References
1	331.52	Ni	331.57	A, F, M, R
2	336.14	Ni	336.16	A, F, M, R
3	336.63	Ni	336.62, 336.58	A, F, M, R
4	337.01	Ni	336.96, 337.20	A, M, R
5	338.13	Ni	338.06, 338.09	A, F, M, R
6	339.37	Ni	339.30, 339.11	A, F, M, R
		Co	339.54	A, F, M, R
7	340.61	Co	340.51	A, F, M, R
8	340.99	Co	340.92	A, F, M, R
9	341.49	Ni	341.48, 341.39, 341.35	A, M, R
		Co	341.23, 341.26, 341.72	A, F, M, R
10	342.48	Ni	342.37	A, F, M, R
11	343.35	Ni	343.36	A, F, M, R
		Co	343.30, 343.16	A, F, M, R
12	343.85	Ni	343.73	A, F, M, R
13	344.72	Ni	344.63	A, F, M, R
		Co	344.92, 344.94, 344.36, 344.29	A, F, M, R
14	345.34	Co	345.35, 345.52	A, F, M, R
		Ni	345.29	A, F, M, R
15	345.96	Ni	345.85	A, F, M, R
16	346.21	Ni	346.17	A, F, M, R
		Co	346.28	A, F, M, R
17	346.58	Co	346.58	A, F, M, R
18	347.32	Ni	347.25	A, F, M, R
		Co	347.40	A, F, M, R
19	348.44	Ni	348.38, 348.59	A, F, M, R
20	348.94	Co	348.94	A, F, M, R
21	349.31	Ni	349.30	A, F, M, R
		Co	349.57	A, F, M, R
22	350.30	Co	350.23	A, F, M, R
		Ni	350.09	A, F, M, R
23	350.67	Co	350.63	A, F, M, R
24	351.05	Ni	351.03	A, F, M, R
		Co	350.98, 351.04, 351.26	A, F, M, R
25	351.54	Ni	351.51	A, F, M, R
		Co	351.35	A, F, M, R
26	352.04	Co	352.16, 352.01	A, F, M, R
		Ni	351.98	A, F, M, R
27	352.53	Ni	352.45	A, F, M, R
		Co	352.34, 352.98, 352.68, 352.90	A, M, R

Table C-19. Spectral Lines of DTFT Exhaust Plume Doped with 50 ppm Rene 41 (continued).

Peak No.	Wavelength (in nm)	Emitter	Contributing Lines (Wavelength in nm)	References
28	354.89	Ni	354.82	A, F, M, R
29	356.74	Ni	356.64	A, F, M, R
		Co	356.94	A, F, M, R
30	357.24	Ni	357.19	A, F, M, R
31	357.61	Co	357.54, 357.50	A, F, M, R
32	357.86	Cr	357.87	A, F, M, R
33	358.85	Ni	358.79	A, M, R
		Co	358.72, 358.52	A, F, M, R
34	359.47	Cr	359.35	A, F, M, R
		Co	359.49	A, F, M, R
35	359.84	Ni	359.77	A, F, M, R
36	360.58	Cr	360.53	A, F, M, R
		Co	360.21	A, F, M, R
37	361.07	Ni	361.05, 361.27	A, F, M, R
38	361.94	Ni	361.94	A, F, M, R
39	367.01	Ni	367.04	A, M, R
40	367.50	Ni	367.41	A, M, R
41	377.61	Ni	377.56	A, F, M, R
42	378.36	Ni	378.35	A, F, M, R
43	380.70	Ni	380.71	A, F, M, R
44	384.51	Co	384.55, 384.20	A, F, M, R
45	385.87	Ni	385.83	A, F, M, R
46	387.34	Co	387.31, 387.40	A, F, M, R
47	389.44	Co	389.41, 389.50	A, F, M, R
48	399.52	Co	399.53, 399.79	A, F, M, R
49	412.05	Co	412.13, 411.88	A, F, M, R
50	425.43	Cr	425.43	A, F, M, R

Table C-20. Spectral Lines of DTFT Exhaust Plume Doped with 50 ppm Waspaloy.

Peak No.	Wavelength (in nm)	Emitter	Contributing Lines (Wavelength in nm)	References
1	331.55	Ni	331.57	A, F, M, R
2	332.30	Ni	332.03, 332.23	A, M, R
3	336.28	Ni	336.16	A, F, M, R
4	336.66	Ni	336.62, 336.58	A, F, M, R
		Co	336.71	A, F, M
5	337.03	Ni	336.96, 337.20	A, M, R
6	338.15	Ni	338.06, 338.09	A, F, M, R
7	339.39	Ni	339.30, 339.11	A, F, M, R
		Co	339.54	A, F, M, R
8	340.64	Co	340.51	A, F, M, R
9	341.01	Co	340.92	A, F, M, R
		Ni	340.96	A, M, R
10	341.51	Ni	341.48, 341.39, 341.35	A, M, R
		Co	341.23, 341.26	A, F, M, R
11	342.50	Ni	342.37	A, F, M, R
12	343.50	Ni	343.36	A, F, M, R
		Co	343.30, 343.16	A, F, M, R
13	343.75	Ni	343.73	A, F, M, R
14	344.74	Ni	344.63	A, F, M, R
15	344.99	Co	344.92, 344.94	A, F, M, R
16	345.36	Co	345.35, 345.52	A, F, M, R
		Ni	345.29	A, F, M, R
17	345.86	Ni	345.85	A, F, M, R
18	346.23	Ni	346.17	A, F, M, R
		Co	346.28	A, F, M, R
19	346.61	Co	346.58	A, F, M, R
20	347.35	Ni	347.25	A, F, M, R
		Co	347.40	A, F, M, R
21	348.47	Ni	348.38, 348.59	A, F, M, R
		Co	348.34	A, F, M, R
22	349.34	Ni	349.30	A, F, M, R
23	350.33	Co	350.23	A, F, M, R
		Ni	350.09	A, F, M, R
24	350.70	Co	350.63	A, F, M, R
25	351.07	Ni	351.03	A, F, M, R
		Co	350.98, 351.04, 351.26	A, F, M, R
26	351.57	Ni	351.51	A, F, M, R
		Co	351.26, 351.35	A, F, M, R
27	352.07	Ni	351.98	A, F, M, R

Table C-20. Spectral Lines of DTFT Exhaust Plume Doped with 50 ppm Waspaloy (continued).

Peak No.	Wavelength (in nm)	Emitter	Contributing Lines (Wavelength in nm)	References
28	352.56	Ni	352.45	A, F, M, R
		Co	352.68, 352.34	A, M, R
29	354.92	Ni	354.82	A, F, M, R
30	356.16	Co	355.06	A, F, M
31	356.78	Ni	356.64	A, F, M, R
		Co	356.50	A, F, M
32	357.27	Ni	357.19	A, F, M, R
33	357.64	Co	357.54, 357.50	A, F, M, R
34	357.89	Cr	357.87	A, F, M, R
35	358.76	Co	358.72, 358.52	A, F, M, R
		Ni	358.79	A, M, R
36	359.50	Cr	359.35	A, F, M, R
		Co	359.49	A, F, M, R
37	359.87	Ni	359.77	A, F, M, R
38	360.24	Co	360.21	A, F, M, R
39	360.62	Cr	360.53	A, F, M, R
40	361.11	Ni	361.05, 361.27	A, F, M, R
41	361.98	Ni	361.94	A, F, M, R
42	367.05	Ni	367.04	A, M, R
43	367.54	Ni	367.41	A, M, R
44	372.12	Fe	371.99, 372.26	A, F, M, R
45	373.72	Fe	373.71, 373.49, 373.33	A, F, M, R
		Ni	373.68	A, M, R
46	377.67	Ni	377.56	A, F, M, R
47	378.41	Ni	378.35	A, F, M, R
48	380.76	Ni	380.71	A, F, M, R
49	384.58	Co	384.55, 384.20	A, F, M, R
50	385.94	Fe	385.99, 385.64	A, F, M, R
		Ni	385.83	A, F, M, R
51	387.42	Co	387.31, 387.40	A, F, M, R
52	389.51	Co	389.41, 389.50	A, F, M, R
53	399.61	Co	399.53, 399.79	A, F, M, R
54	403.42	Mn	403.08, 403.31, 403.45	A, F, M, R
55	412.16	Co	412.13, 411.88	A, F, M, R
56	425.56	Cr	425.43	A, F, M, R

Table C-21. Spectral Lines of DTFT Exhaust Plume Doped with 100 ppm Tens 50 Aluminum.

Peak No.	Wavelength (in nm)	Emitter	Contributing Lines (Wavelength in nm)	References
1	394.43	Al	394.40	A, F, M, R
2	396.16	Al	396.15	A, F, M, R
3	404.41	K	404.41, 404.72	A, F, M, R

Table C-22. Spectral Lines of DTFT Exhaust Plume Doped with 100 ppm 6061 Aluminum.

Peak No.	Wavelength (in nm)	Emitter	Contributing Lines (Wavelength in nm)	References
1	324.71	Cu	324.75	A, F, M, R
2	327.32	Cu	327.40	A, F, M, R
3	371.92	Fe	371.99, 372.26	A, F, M, R
4	373.65	Fe	373.71, 373.49, 373.33	A, F, M, R
5	374.52	Fe	374.56, 374.59	A, F, M, R
6	386.03	Fe	385.99	A, F, M, R
7	394.43	Al	394.40	A, F, M, R
8	396.16	Al	396.15	A, F, M, R
9	403.30	Mn	403.08, 403.31, 403.45	A, F, M, R
10	404.41	K	404.41	A, F, M, R
11	404.78	K	404.72	A F, M, R
12	425.48	Cr	425.43	A, F, M, R

Table C-23. Spectral Lines of DTFT Exhaust Plume Doped with 50 ppm Incoloy 88.

Peak No.	Wavelength* (in nm)	Emitter	Contributing Lines (Wavelength in nm)	References
1	324.71	Cu	324.75	A, F, M, R
2	327.32	Cu	327.40	A, F, M, R
3	336.89	Ni	336.96, 337.20	A, M, R
4	338.01	Ni	338.06, 338.09	A, F, M, R
5	339.13	Ni	339.30, 339.11	A, F, M, R
6	341.37	Ni	341.48, 341.39, 341.35	A, M, R
7	342.24	Ni	342.37	A, F, M, R
8	343.23	Ni	343.36	A, F, M, R
9	343.60	Ni	343.73	A, F, M, R
10	343.98	Fe	344.06, 344.10	A, F, M, R
11	344.47	Fe	344.39	A, F, M, R
		Ni	344.63	A, F, M, R
12	345.22	Ni	345.29	A, F, M, R
13	345.72	Ni	345.85	A, F, M, R
14	346.09	Ni	346.17	A, F, M, R
15	346.46	Fe	346.59	A, F, M, R
16	347.21	Ni	347.25	A, F, M, R
17	347.46	Fe	347.55, 347.67, 347.65	A, R
18	348.33	Ni	348.38, 348.59	A, F, M, R
19	349.20	Ni	349.30	A, F, M, R
		Fe	349.06	A, F, M, R
20	349.69	Fe	349.78	A, F, M, R
21	349.94	Ni	350.09	A, F, M, R
22	350.94	Ni	351.03	A, F, M, R
23	351.43	Ni	351.51	A, F, M, R
24	351.93	Ni	351.98	A, F, M, R
25	352.43	Ni	352.45	A, F, M, R
		Fe	352.60, 352.62	A, F, M, R
26	354.67	Ni	354.82	A, F, M, R
27	356.53	Ni	356.64	A, F, M, R
		Fe	356.54	A, F, M, R
28	357.02	Ni	357.19	A, F, M, R
		Fe	357.01, 357.03	M, R
29	357.77	Cr	357.87	A, F, M, R
		Fe	358.12	A, F, M, R
30	358.64	Ni	358.79	A, M, R

Table C-23. Spectral Lines of DTFT Exhaust Plume Doped with 50 ppm Incoloy 88 (continued).

Peak No.	Wavelength* (in nm)	Emitter	Contributing Lines (Wavelength in nm)	References
31	359.26	Cr	359.35	A, F, M, R
32	359.76	Ni	359.77	A, F, M, R
33	360.50	Cr	360.53	A, F, M, R
34	361.00	Ni	361.05, 361.27	A, F, M, R
		Fe	360.89, 361.02	M, R
35	361.87	Ni	361.94	A, F, M, R
		Fe	361.88	A, F, M, R
36	363.11	Fe	363.15	A, F, M, R
37	364.72	Fe	364.78, 364.95	M, R
38	367.95	Fe	367.99, 368.22	M, R
39	370.55	Fe	370.56, 370.79, 370.78	M, R
40	371.92	Fe	371.99, 372.26	A, F, M, R
41	373.65	Fe	373.71, 373.49, 373.33	A, F, M, R
42	374.52	Fe	374.56, 374.59	A, F, M, R
43	374.77	Fe	374.95, 374.83	A, F, M, R
44	375.76	Fe	375.82, 376.00	M, R
45	376.38	Fe	376.38, 376.55	F, M, R
46	376.63	Fe	376.72	A, F, M, R
47	377.49	Ni	377.56	A, F, M, R
48	378.36	Ni	378.35	A, F, M, R
49	380.71	Ni	380.71	A, F, M, R
50	382.07	Fe	382.04, 382.12	M, R
51	382.45	Fe	382.44, 382.59, 382.78	A, F, M, R
52	383.43	Fe	383.42	A, F, M, R
53	384.05	Fe	384.10, 384.04, 383.93	M, R
54	385.91	Fe	385.99, 385.64	A, F, M, R
		Ni	385.83	A, F, M, R
55	387.89	Fe	387.86, 387.80	A, F, M, R
56	388.63	Fe	388.63, 388.70	M, R
57	389.49	Fe	389.57	A, F, M, R
58	389.99	Fe	389.97, 390.29	A, F, M, R
59	390.60	Fe	390.65	A, F, M, R
60	392.33	Fe	392.29, 392.03	A, F, M, R
61	392.95	Fe	393.03, 392.79	A, F, M, R
62	403.05	Mn	403.08	A, F, M, R

Table C-23. Spectral Lines of DTFT Exhaust Plume Doped with 50 ppm Incoloy 88 (continued).

Peak No.	Wavelength* (in nm)	Emitter	Contributing Lines (Wavelength in nm)	References
63	403.30	Mn	403.31, 403.45	A, F, M, R
64	404.41	K	404.41, 404.72	A, F, M, R
		Fe	404.58	A, F, M, R
65	425.36	Cr	425.43	A, F, M, R

* Wavelength calibration off approximately 0.1 nm.

Table C-24. Spectral Lines of DTFT Exhaust Plume Doped with 50 ppm Elgiloy.

Peak No.	Wavelength* (in nm)	Emitter	Contributing Lines (Wavelength in nm)	References
1	336.89	Ni	336.96, 337.20	A, M, R
2	338.01	Ni	338.06, 338.09	A, F, M, R
3	338.38	Co	338.52	A, F, M
4	339.13	Ni	339.30, 339.11	A, F, M, R
		Co	339.54	A, F, M, R
5	340.37	Co	340.51	A, F, M, R
6	340.87	Co	340.92	A, F, M, R
7	341.12	Co	341.23, 341.26, 341.72	A, F, M, R
		Ni	341.48, 341.39, 341.35	A, M, R
8	342.24	Ni	342.37	A, F, M, R
9	343.23	Co	343.30, 343.16	A, F, M, R
		Ni	343.36	A, F, M, R
10	343.60	Ni	343.73	A, F, M, R
11	343.98	Fe	344.06, 344.10	A, F, M, R
12	344.23	Co	344.36, 344.29	A, F, M, R
		Fe	344.39	A, F, M, R
		Ni	344.63	A, F, M, R
13	344.85	Co	344.92, 344.94	A, F, M, R
14	345.22	Co	345.35, 345.52	A, F, M, R
		Ni	345.29	A, F, M, R
15	345.72	Ni	345.85	A, F, M, R
16	346.09	Ni	346.17	A, F, M, R
		Co	346.28	A, F, M, R
17	346.46	Co	346.58	A, F, M, R
		Fe	346.59	A, F, M, R
18	347.33	Co	347.40	A, F, M, R
		Ni	347.25	A, F, M, R
		Fe	347.55, 347.67, 347.65	A, R
19	348.33	Ni	348.38, 348.59	A, F, M, R
		Co	348.34	A, F, M, R
20	349.20	Ni	349.30	A, F, M, R
		Co	349.57, 348.94	A, F, M, R
		Fe	349.06	A, F, M, R
21	350.19	Co	350.23	A, F, M, R
		Ni	350.09	A, F, M, R
22	350.56	Co	350.63	A, F, M, R
23	350.94	Co	350.98, 351.04	A, F, M, R
		Ni	351.03	A, F, M, R
24	351.31	Ni	351.51	A, F, M, R
		Co	351.26, 351.35	A, F, M, R

Table C-24. Spectral Lines of DTFT Exhaust Plume Doped with 50 ppm Elgiloy (continued).

Peak No.	Wavelength* (in nm)	Emitter	Contributing Lines (Wavelength in nm)	References
25	352.43	Ni	352.45	A, F, M, R
		Co	352.34, 352.16, 352.01	A, M, R
26	352.92	Co	352.98, 352.68, 352.90	A, F, M, R
27	353.30	Co	353.34	A, F, M, R
28	355.04	Co	355.06	A, F, M
29	356.03	Co	356.09	A, F, M, R
30	356.53	Ni	356.64	A, F, M, R
		Co	356.50	A, F, M
31	356.90	Co	356.94	A, F, M, R
		Ni	357.19	A, F, M, R
		Fe	357.01, 357.03	M, R
32	357.52	Co	357.54, 357.50	A, F, M, R
33	357.77	Cr	357.87	A, F, M, R
		Fe	358.12	A, F, M, R
34	358.64	Co	358.72, 358.52	A, F, M, R
35	359.26	Cr	359.35	A, F, M, R
		Co	359.49	A, F, M, R
		Ni	359.77	A, F, M, R
36	360.13	Co	360.21	A, F, M, R
37	360.50	Cr	360.53	A, F, M, R
38	361.00	Ni	361.05, 361.27	A, F, M, R
		Fe	360.89, 361.02	M, R
39	361.87	Ni	361.94	A, F, M, R
		Fe	361.88	A, F, M, R
40	362.74	Co	362.78	A, F, M, R
41	363.11	Fe	363.15	A, F, M, R
		Co	363.14	A, F, M
42	364.72	Fe	364.78, 364.95	M, R
43	365.22	Co	365.25	A, F, M
44	367.95	Fe	367.99, 368.22	M, R
45	370.55	Fe	370.56, 370.79, 370.78	M, R
46	370.80	Fe	370.92	A, M, R
47	371.92	Fe	371.99, 372.26	A, F, M, R
48	373.65	Fe	373.71, 373.49, 373.33	A, F, M, R
49	374.52	Fe	374.56, 374.59, 374.95, 374.83	A, F, M, R
50	375.76	Fe	375.82, 376.00	M, R
51	378.36	Ni	378.35	A, F, M, R
52	380.71	Ni	380.71	A, F, M, R

Table C-24. Spectral Lines of DTFT Exhaust Plume Doped with 50 ppm Elgiloy (continued).

Peak No.	Wavelength* (in nm)	Emitter	Contributing Lines (Wavelength in nm)	References
53	382.07	Fe	382.04, 382.12	M, R
54	382.45	Fe	382.44, 382.58, 382.78	A, F, M, R
55	383.43	Fe	383.42	A, F, M, R
56	384.18	Fe	384.10, 384.04, 383.93	M, R
57	384.55	Co	384.55, 384.20	A, F, M, R
58	386.03	Fe	385.99, 385.64	A, F, M, R
		Ni	385.83	A, F, M, R
59	387.39	Co	387.31, 387.40	A, F, M, R
60	387.89	Fe	387.86, 387.80	A, F, M, R
61	388.13	Co	388.19	A, F, M, R
62	388.63	Fe	388.63, 388.70	M, R
63	389.49	Co	389.41, 389.50	A, F, M, R
		Fe	389.57	A, F, M, R
64	389.99	Fe	389.97, 390.29	A, F, M, R
65	390.97	Co	390.99	A, F, M
66	392.33	Fe	392.29, 392.03	A, F, M, R
67	393.07	Fe	393.03, 392.79	A, F, M, R
68	393.69	Co	393.60	A, F, M, R
69	398.01	Co	397.95, 397.87	A, F, M
70	399.61	Co	399.53, 399.79	A, F, M, R
71	403.42	Mn	403.08, 403.31, 403.45	A, F, M, R
72	404.41	K	404.41, 404.72	A, F, M, R
73	409.32	Co	409.24	A, F, M, R
74	412.15	Co	412.13, 411.88	A, F, M, R
75	419.13	Co	419.07	A, F, M, R
76	425.48	Cr	425.43	A, F, M, R

* Wavelength calibration off approximately 0.1 nm.

Table C-25. Spectral Lines of DTFT Exhaust Plume Doped with 50 ppm Nitriding Steel.

Peak No.	Wavelength* (in nm)	Emitter	Contributing Lines (Wavelength in nm)	References
1	343.98	Fe	344.06, 344.10, 344.39	A, F, M, R
2	346.46	Fe	346.59	A, F, M, R
3	347.46	Fe	347.55, 347.67, 347.65	A, R
4	348.95	Fe	349.06	A, F, M, R
5	349.69	Fe	349.78	A, F, M, R
6	352.55	Fe	352.60, 352.62	A, F, M, R
7	356.40	Fe	356.54	A, F, M, R
8	356.90	Fe	357.01, 357.03	M, R
9	358.02	Fe	358.12	A, F, M, R
		Cr	357.87	A, F, M, R
10	358.76	Fe	358.70, 358.61	M, R
11	359.26	Cr	359.35	A, F, M, R
12	360.50	Cr	360.53	A, F, M, R
13	360.88	Fe	360.89, 361.02	M, R
14	361.87	Fe	361.88	A, F, M, R
15	363.11	Fe	363.15	A, F, M, R
16	364.72	Fe	364.78, 364.95	M, R
17	367.95	Fe	367.99, 368.22	M, R
18	368.69	Fe	368.75, 368.60	M, R
19	370.55	Fe	370.56, 370.79, 370.78, 370.92	M, R
20	371.92	Fe	371.99, 372.26	A, F, M, R
21	373.65	Fe	373.71, 373.49, 373.33	A, F, M, R
22	374.52	Fe	374.56, 374.59	A, F, M, R
23	374.89	Fe	374.95, 374.83	A, F, M, R
24	375.76	Fe	375.82, 376.00	M, R
25	376.38	Fe	376.38, 376.55	F, M, R
26	376.75	Fe	376.72	A, F, M, R
27	379.48	Fe	379.50, 379.75	M, R
28	379.85	Fe	379.95, 379.85	A, M, R
29	381.58	Fe	381.58, 381.30, 381.31	M, R
30	382.07	Fe	382.04, 382.12	M, R
31	382.45	Fe	382.44, 382.59, 382.78	A, F, M, R
32	383.43	Fe	383.42	A, F, M, R
33	384.05	Fe	384.10, 384.04, 383.93	M, R

Table C-25. Spectral Lines of DTFT Exhaust Plume Doped with 50 ppm Nitriding Steel (continued).

Peak No.	Wavelength* (in nm)	Emitter	Contributing Lines (Wavelength in nm)	References
34	385.66	Fe	385.64	A, F, M, R
35	386.03	Fe	385.99	A, F, M, R
36	387.27	Fe	387.25, 387.38	M, R
37	387.89	Fe	387.86, 387.80	A, F, M, R
38	388.63	Fe	388.63, 388.70	M, R
39	389.62	Fe	389.57	A, F, M, R
40	389.99	Fe	389.97, 390.29	A, F, M, R
41	390.73	Fe	390.65	A, F, M, R
42	392.33	Fe	392.29, 392.03	A, F, M, R
43	393.07	Fe	393.03, 392.79	A, F, M, R
44	403.30	Mn	403.08, 403.31, 403.45	A, F, M, R
45	404.65	K	404.41, 404.72	A, F, M, R
		Fe	404.58	A, F, M, R
46	406.38	Fe	406.36	A, F, M, R
47	407.24	Fe	407.17	A, F, M, R
48	425.48	Cr	425.43	A, F, M, R

* Wavelength calibration off approximately 0.1 nm.

Table C-26. Spectral Lines of DTFT Exhaust Plume Doped with 100 ppm 2024 Aluminum.

Peak No.	Wavelength (in nm)	Emitter	Contributing Lines (Wavelength in nm)	References
1	324.66	Cu	324.75	A, F, M, R
2	327.40	Cu	327.40	A, F, M, R
3	371.94	Fe	371.99, 372.26	A, F, M, R
		MgOH	371.9	A, F
4	373.67	Fe	373.71, 373.49, 373.33	A, F, M, R
5	374.53	Fe	374.56, 374.59	A, F, M, R
6	374.90	Fe	374.95, 374.83	A, F, M, R
7	382.05	Fe	382.04, 382.12	M, R
		MgO(H)	382.2, 382.3	A, F
8	385.99	Fe	385.99	A, F, M, R
9	388.57	Fe	388.63, 388.70	M, R
10	394.36	Al	394.40	A, F, M, R
11	396.08	Al	396.15	A, F, M, R
12	402.96	Mn	403.08	A, F, M, R
13	403.33	Mn	403.31, 403.45	A, F, M, R
14	404.31	K	404.41, 404.72	A, F, M, R
15	425.43	Cr	425.43	A, F, M, R

Table C-27. Spectral Lines of DTFT Exhaust Plume Doped with 100 ppm A356 Aluminum.

Peak No.	Wavelength (in nm)	Emitter	Contributing Lines (Wavelength in nm)	References
1	324.71	Cu	324.75	A, F, M, R
2	327.32	Cu	327.40	A, F, M, R
3	372.04	Fe	371.99, 372.26	A, F, M, R
4	373.65	Fe	373.71, 373.49, 373.33	A, F, M, R
5	385.91	Fe	385.99	A, F, M, R
6	394.43	Al	394.40	A, F, M, R
7	396.16	Al	396.15	A, F, M, R
8	403.18	Mn	403.08, 403.31, 403.45	A, F, M, R
9	404.41	K	404.41, 404.72	A, F, M, R

Reference Note

The letter codes used in the preceding tables refer to the following references. The references are repeated here for the reader's convenience. The number shown for each reference given below refers to that reference as it is mentioned in the main text of this report and as it is numbered in the complete reference list.

Code	Reference Number	Reference
A	11	C. Th. J. Alkemade and R. Herrmann, *Fundamentals of Analytical Flame Spectroscopy*, Wiley, New York, NY, 1979.
F	18	R. Mavrodineanu and H. Boiteux, *Flame Spectroscopy*, Wiley, New York, NY, 1965.
M	15	F.M. Phelps, *M.I.T. Wavelength Tables, Volume 2: Wavelengths by Element*, M.I.T. Press, Cambridge, MA 1982.
R	17	J. Reader, C.H. Corliss, W.L. Wiese, and G.A. Martin, *Wavelengths and Transition Probabilities for Atoms and Atomic Ions, Part I. Wavelengths, Part II. Transition Probabilities*, NSRDS–NBS 68, U.S. Govt. Printing Office, Washington, DC, 1980.

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13. ABSTRACT *(Maximum 200 words)*

Stennis Space Center (SSC) is pursuing the advancement of experimental techniques and theoretical developments in the field of plume spectroscopy for application to rocket development testing programs and engine health monitoring. Exhaust plume spectral data for the Space Shuttle Main Engine (SSME) are routinely acquired. The usefulness of this data depends upon qualitative and quantitative interpretation of spectral features and their correlation with the engine performance. A knowledge of the emission spectral characteristics of effluent materials in the exhaust plume is essential. A study of SSME critical components and their materials identified 30 elements and 53 materials whose engine exhaust plume spectra might be required. The most important have been evaluated using SSC's Diagnostic Testbed Facility Thruster (DTFT), a 1200-lbf, liquid oxygen/gaseous hydrogen rocket engine which very nearly replicates the temperature and pressure conditions of the SSME exhaust plume in the first Mach diamond. This report presents the spectral data for the 10 most important elements and 27 most important materials which are strongly to moderately emitting in the DTFT exhaust plume. The covered spectral range is 300 to 426 nm and the spectral resolution is 0.25 nm. Spectral line identification information is provided and line interference effects are considered.

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